Desktop Estimation of Yield for Aquifer Storage Recovery Schemes

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By applying yield – reliability assessment techniques, it is possible to examine the scale of pre-storage and aquifer storage required for a proposed Aquifer Storage and Recovery (ASR) scheme, and derive a useful estimation of the yield from the scheme. This information can provide clear indications of the feasibility of the scheme from a hydraulic and infrastructure perspective prior to undertaking further field investigations. It can also show that it is not necessarily aquifer characteristics that control the overall feasibility or even the yield of the scheme. This paper presents a step by step methodology for preliminary sizing and yield assessment of ASR schemes using commonly available data and desktop analysis techniques.

1. INTRODUCTION

Aquifer Storage Recovery (ASR) schemes have gained widespread acceptance as an alternative water supply source. Hydrogeologists may be asked to provide guidance on the suitability of ASR in a range of circumstances, from large scale harvesting of rivers to capture and storage of regional stormwater flows. Aquifers can be expensive to investigate, and there is no guarantee that the findings will be favorable. Hence, hydrogeologists are often required to give initial guidance in the context of limited data.

One of the issues that must be addressed in such a feasibility assessment is the quantity of water that the ASR scheme will provide – the 'yield'. In this paper, it is argued that the estimation of yield must recognize the dynamics of the ASR scheme, and an examination of aquifer characteristics alone is not sufficient.

A methodology that offers a first pass examination of yield of an ASR scheme is presented in this paper, and is based on yield-reliability analyses which are common to the water resources engineering or surface water hydrology sectors.

2. OVERVIEW OF ASR – A HYDRAULIC PERSPECTIVE

Aquifer Storage and Recovery (ASR) is commonly defined as a scheme that involves the controlled storage of water in an aquifer during times when water is available, and recovery of that water when it is needed. ASR is a water supply technique that involves using aquifers as a storage reservoir for the capture of surface water flows.

There are variations in the way that ASR schemes are applied, but the key principle is that by offering storage, the natural variability of source flows can be buffered to provide a more regular output flow – that is, a more reliable water supply.

An immediately appreciable example of ASR is in arid or strongly seasonal climates, where "times of plenty" (flood events or wet seasons) contrast sharply against dry periods - in this case, water is captured and stored during the wet season in anticipation for the regular dry season. ASR can also be applied to other climates where variability occurs on a shorter or less predictable time basis. Weekly or daily fluctuations in source flows from a catchment may be captured, and a regular year-round output flow may be delivered by managing aquifer recharge and discharge on a more dynamic basis. In these cases, the concept of "storage for a time of need" is not as pronounced, but it nonetheless remains the key principle behind the yield that the scheme offers.

For an ASR water supply scheme to be successful, it requires the somewhat serendipitous co-occurrence of: a suitable supply source (catchment outflows); a suitable demand (a local use for the water), and; aquifer conditions that are suitable. It will also require development of supporting infrastructure, the costs of which need to be weighed up against the benefits of obtaining a new water source.

The key components of an ASR scheme are depicted in Figure 1. Catchment outflows occur in response to variable rainfall patterns. A portion of this flow is captured and redirected to the aquifer storage and is released as required to meet demands.

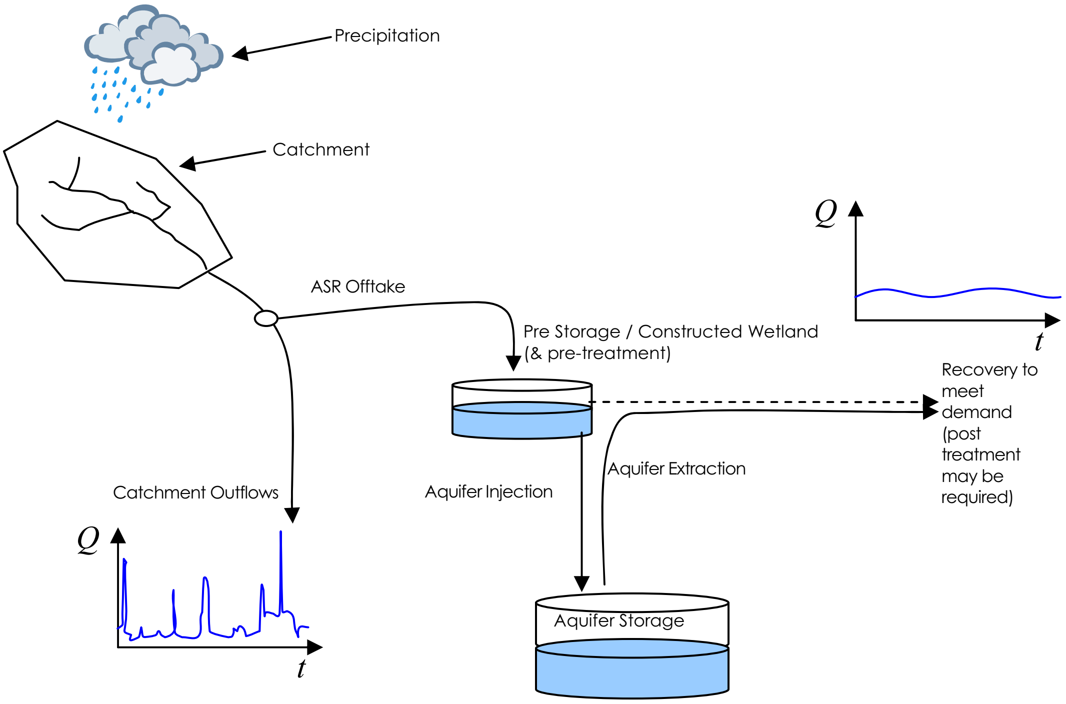
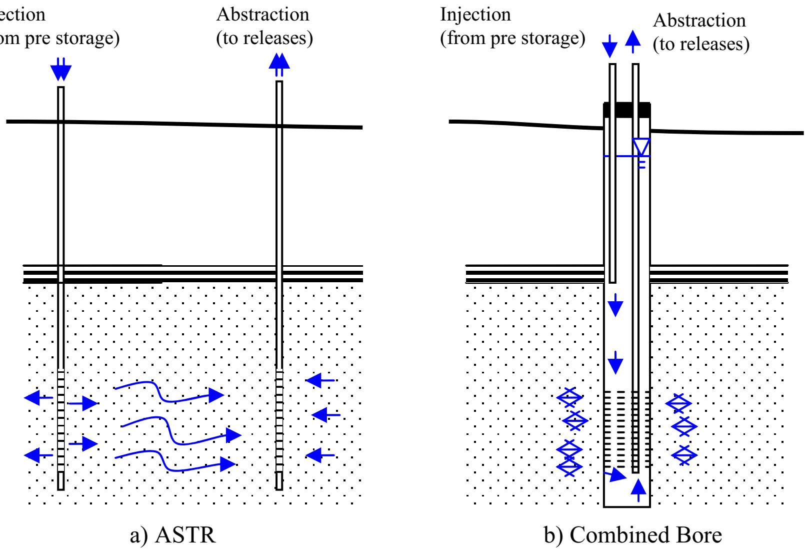


Figure 1 Conceptual Schematic of an ASR Scheme

Water is directed to aquifer storage by surface infiltration, or by application of injection wells. In practice, the rate of recharge into the aquifer is much smaller than the discharges that the scheme seeks to capture from the catchment – particularly if the objective is to capture storm events. Hence it is common to construct a pre-storage (as shown) that assists in capturing an acceptable portion of the rainfall hydrograph and allowing a controlled discharge to the aquifer that continues after the rainfall event has passed.

It is evident then that the volume of water that the ASR scheme can deliver (the yield) is the result of dynamic interactions between issues of catchment flow variability, infrastructure capacities (storage volumes and treatment processes), aquifer properties and demand. The yield is also a function of the scheme arrangement and operational rules that are adopted. In the example shown in Figure 1, pipe and bore infrastructure could be detailed so that aquifer recharge and extraction could occur simultaneously. This could be done by construction of separate borefields for injection and for abstraction but which access the same aquifer (this is referred to as ASTR – aquifer storage transfer and recovery – see Figure 2a). Alternatively, infrastructure could be detailed so that the injection line and abstraction line could share a common bore (see Figure 2b). There are other alternatives (such as represented by the dotted line in Figure 1), but these are not addressed in this paper.

In Figure 1, the aquifer is represented as a tank. This is a simplistic representation, but is a key assumption behind the method set out in this paper. For many ASR schemes, water that is purposefully directed to the aquifer is 'seen' as a separate resource to any existing groundwater – hence the hydraulic role of the aquifer in an ASR scheme is similar to a tank, albeit perhaps a leaky one.



a) ASTR b) Combined Bore

Figure 2 Two Aquifer Injection and Extraction Options

3. CURRENT GUIDANCE ON PLANNING ASR SCHEMES

In Australia, a "*Code of Practice for Aquifer Storage and Recovery"* (EPA, South Australia, 2004) provides authoritative guidance for assessment of the economic feasibility of an ASR scheme. This guidance places emphasis on cost items associated with water quality criteria, which is necessary to protect the environmental values of the aquifer, ensure against bore clogging and provide a suitable standard of supply water. It is the author's understanding that this emphasis on water quality and environmental issues is reflected generally in industry approaches to assessment of ASR schemes.

Without a doubt, the infrastructure required to ensure the protection of aquifer environmental values and the delivery of appropriately treated water are key cost items that can define the feasibility of a scheme. However, it is difficult to appraise economic viability if the only commodity that is produced – the yield – is not appraised also.

It is noted that in many papers and reports on ASR schemes, when describing the 'scale' of a scheme, reference is given to volumes of water that the scheme may store, the aquifer transmissivity or the bore pumping capacity. With respect to the dynamics of the system depicted in Figure 1, it is clear that these items in themselves do not always adequately describe the yield. On the contrary, for many systems the aquifer size may be a poor representation of the yield of the ASR scheme.

This paper sets out a methodology to assess yield, which is defined as a *discharge* of water that can be sustained at an assessed probability of failure over a defined period of time.

4. DESKTOP YIELD APPRAISAL OF ASR SCHEMES

In this section, the principles of yield assessments are presented, and a step-by-step methodology is given. Examples of the application of this method are given in Section 5.

4.1. System Representation

For the purposes of the analyses presented in this paper, an ASR system has been characterized as shown in Figure 3. The terms are explained in Table 1.

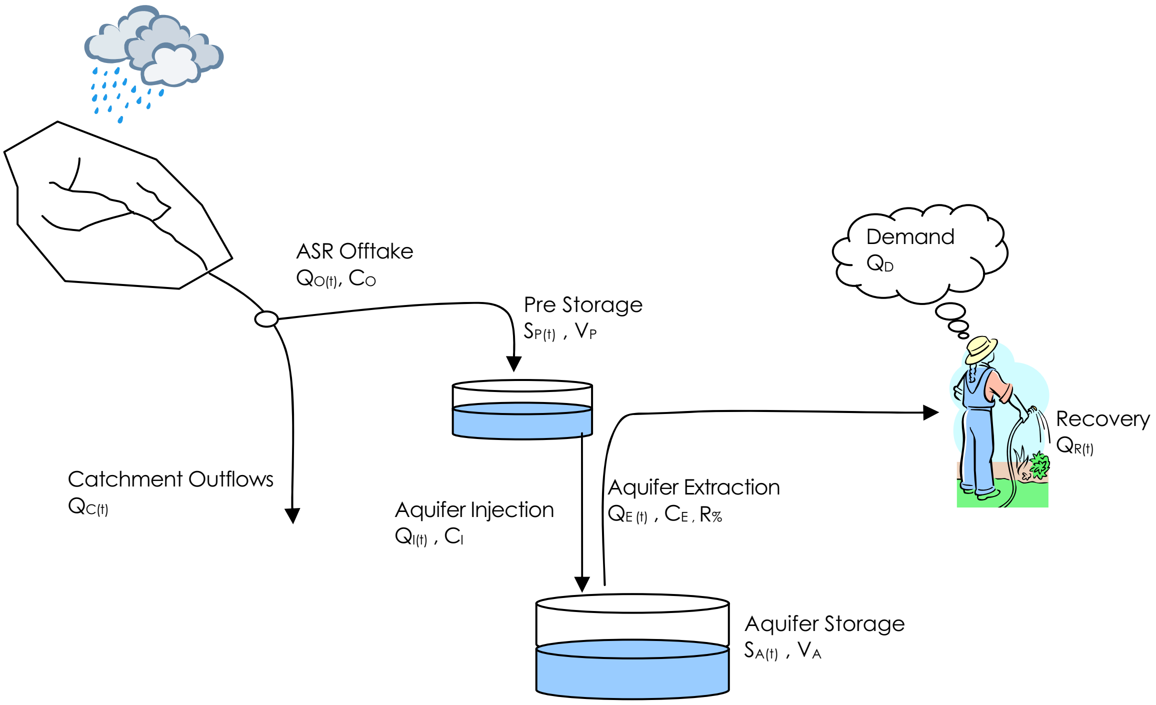


Figure 3 Generic Representation of ASR Schemes for Yield-Reliability Modelling

Table 1. Explanation of Terms Used in ASR System Analysis

Component	**Symbols**	**Explanation**
Catchment Outflow *(volume/time)*	$Q_{C(t)}$	The catchment outflow is a timeseries of discharges ("streamflows") from the catchment. It should be noted that this timeseries represents the ambient or long-term catchment outflow characteristics, not a flood or event hydrograph.
ASR Offtake *(volume/time)*	$Q_{O(t),}$ C_O	The ASR Offtake discharge ($Q_{O(t),}$) is a timeseries of discharges that is harvested from the catchment outflow ($Q_{C(t)}$). The offtake for the ASR scheme will usually comprise a constructed channel or pipe and a diversion structure. This infrastructure may introduce restrictions to the discharge that can be carried. The maximum discharge that the ASR Offtake can carry is denoted C_O. Where only the ASR Offtake capacity (C_O) is defined, the ASR Offtake discharge ($Q_{O(t),}$) will simply reflect the catchment outflow ($Q_{C(t)}$) but with an upper limit. ASR Offtake discharge ($Q_{O(t),}$) may also reflect more complex operational arrangements, such as harvesting only when catchment outflows are above a certain threshold (ie just harvesting of flood events, or making allowances for environmental flows from the catchment).
Pre-Storage *(volume)*	$S_{P(t)}$, V_P	The volume of the pre-storage tank is denoted V_P. The volume of water inside the storage at any timestep 't' is denoted $S_{P(t)}$.
Aquifer Injection *(volume/time)*	$Q_{I(t)}$, C_I,	The maximum discharge that can be delivered into the aquifer in a single timestep is denoted C_I. This value depends on the aquifer characteristics, pump and infrastructure sizes, and the diameter, depth and number of bores than may be installed. $Q_{I(t)}$ denotes the actual discharge that is delivered at any timestep 't'.
Recovery *(percentage)*	$R_{\%}$	Many ASR schemes, the volume of water that can be recovered is less than the volume that is sent to storage. R% is the ratio of injected water that can be recovered – ie R% = $Q_{E(t)}$ / $Q_{I(t)}$. In this paper, $R_{\%}$ is selected as

		a constant.
Aquifer Extraction *(volume/time)*	$Q_{E(t)}$, C_E	The maximum discharge that can be drawn from the aquifer in a single timestep is denoted C_E. This value depends on the aquifer characteristics, pump and infrastructure sizes, and the diameter, depth and number of bores than may be installed. $Q_{E(t)}$ denotes the actual discharge that is delivered at any timestep 't'.
Aquifer Storage *(volume)*	$S_{A(t)}$, $V_{A,}$ $S_{A(t=0)}$	The volume of the aquifer system is denoted V_A. The volume of water of suitable quality inside the storage at any timestep 't' is denoted $S_{A(t)}$. $S_{A(t=0)}$ is the volume of water that is in the aquifer at the start of the scheme. It is common for ASR schemes to pre-charge the aquifer prior to commencing operation, and this value can influence the yield or reliability of the scheme.
Demand *(volume/time)*	$Q_{D(t)}$	The demand is the discharge that is desired from the scheme. For example, if the ASR Scheme is to supply water to a town, it is the quantity of water, per timestep, that water consumers in that town desire to access. In practice, demand can vary with time, such as in response to seasons or peak / off peak loading. Alternatively, schemes that are initiated to meet demands only during periods of drought or defined seasons will have demands that are only imposed at those defined times.
Recovery *(volume/time)*	$Q_{R(t)}$	The recovery is the discharge that the scheme actually delivers at any timestep 't'.

4.2. Equations

Equations for 'yield-reliability' assessments used in this paper are shown in Equations (1) and (2):

$$\text{Yield "Y" (over a time period T)} = \sum_{0}^{T} Q_{R(t)} \tag{1}$$

The reliability is the probability that recovery at any time 't' ($Q_{R(t)}$) will meet demand ($Q_{D(t)}$). Such recovery can be made only when there is sufficient storage to deliver the demand discharge over the timestep in question. Hence the equation for reliability becomes:

$$\alpha = P(S_{(t)} > Q_{D(t)}.\Delta t) \tag{2}$$

Where P is the probability, and $S_{(t)}$ represents the storage, either $S_{A(t)}$ or $S_{P(t)}$ or ($S_{A(t)} + S_{P(t)}$), depending on the configuration of the scheme.

The reliability can be assessed by counting the number of timesteps over a period T (such as 1 year) for which the full demand is met, and dividing by the total number of timesteps over that period.

Storages in each 'tank' at time 't' are taken as the storage from the previous timestep, plus the sum or inputs and outputs over the current timestep:

$$S_{P(t)} = S_{P(t-1)} + \Delta t.(Q_{O(t).} - Q_{I(t)}) \text{ for } 0 < S_{P(t)} < V_P \tag{3}$$

$$S_{A(t)} = S_{A(t-1)} + \Delta t.(Q_{I(t).} - Q_{E(t)}) \text{ for } 0 < S_{A(t)} < V_A \tag{4}$$

The ASR Offtake discharge $Q_{O(t)}$ is a timeseries that is defined for the entire simulation by applying operational criteria to the catchment outflows. For example, if the ASR Offtake capacity is the only criteria applied, then s

$$Q_{O(t)} = \textbf{minimum}(Q_{C(t)}, C_O) \tag{5}$$

The aquifer injection and abstraction patterns are typically based on a number of logic statements, which reflect the operational details of the system. The aquifer injection discharge $Q_{I(t)}$ can only be delivered when sufficient storage is available on the extraction side, and sufficient storage space is on the receiving side.

$$Q_{I(t)} = (\textbf{minimum}[C_I, S_{P(t-1)}, (V_A - S_{A(t-1)})]) \qquad (6)$$

Lastly, for the case where the aquifer extraction discharge is delivered directly to meet the demand, it can be expressed according to the following:

$$Q_{E(t)} = (\textbf{minimum}[Q_{D(t)}, Q_{I(t)}+S_{A(t-1)}]) \text{ where } S_{A(t)} \text{ is depreciated by } R_{\%} \qquad (7)$$

The equations above are based on the variables presented in Table 1 and the scheme set out in Figure 3. These are presented to communicate the principles of the analysis. Alternative schemes may require the addition or removal of variables, or the alteration of equations.

4.3. Methodology

The equations presented above are relatively simple, and are well suited to being solved using standard spreadsheet applications. However, when planning a new ASR scheme, many of the components listed in Table 1 will be unknown. Desktop estimations of likely component sizes (particularly aquifer storage volumes) are likely to be inaccurate, and the yield is sensitive to the values chosen. In short, solving these equations for a single ‘estimated’ ASR scheme configuration is unlikely to result in a meaningful assessment of yield.

On the other hand, the yield that can be developed from the scheme is not unbounded. The magnitude and dynamics of catchment outflows impose bounds on the yield that is obtainable, and when the catchment outflow are subject to a reasonable restriction (to produce the ASR Offtake discharge), and is routed through a pre-storage of plausible size, the possibilities become limited. It becomes clear that, for a given catchment, there is a limited range of useful pre-storage sizes. Pre-storages that are too small will choke the available yield, they are clearly inefficient. Alternatively, diminishing returns are gained for pre-storages above a certain size, and there are often real-world restrictions to the size of pre-storage that can be developed.

Aquifer's storage volumes usually cannot be known with confidence at the desktop level. However, the relationship between possible aquifer storage volumes and yield can nonetheless be examined with a parametric analysis.

In summary, by fixing some variables, undertaking a parametric analysis of others and considering macro-scale real-world restrictions, a plausible scheme configuration takes form.

A proposed methodology for undertaking such parametric analyses for any proposed ASR scheme is set out below. Examples of the application of this approach are then given in Section 5.

Step 1 – Estimate Aquifer Characteristics.
Undertake a desktop appraisal of aquifer conditions and develop a conceptual hydrogeological model. This should include review of local geological sheet, maps and any available groundwater or registered bore databases that exist. Identify a preferred aquifer system to be accessed for ASR.

Assess likely maximum aquifer injection (C_I) and extraction rates with respect to the possible aquifer system and the number and nature of bores that may be used. Prepare a list of 5 or 6 aquifer injection rates that reflect the findings of the aquifer appraisals.

Prepare a list of 5 or 6 possible aquifer storage volumes that reflect the realms of possibility for the site. This can be performed by referencing known values, or by assuming an areal extent of the aquifer system, an acceptable drawdown range and possible storativity / specific yield values based on the aquifer material. It is acknowledged that estimations will be within orders of magnitude and the range of aquifer storages in the list should reflect this.

Step 2 – Obtain Catchment Streamflow Timeseries $Q_{C(t)}$
Streamflows for the catchment in question ($Q_{C(t)}$) can be based on real (gauged) data, or can be synthesized from modeling of the catchment using historical rainfall records. The temporal distribution of catchment discharges has a strong influence on the assessed yield of the ASR scheme, and hence longer records will offer more confident assessments. Accurate records with short timesteps will also support more accurate analyses, although for this modeling, daily timesteps are usually appropriate. Consideration should be given to the potential impacts of climate change on streamflow discharge or variability.

Step 3 – Define scheme yield objectives and assess demand
Assess scheme objectives with respect to the water demands that are sought. Specify the reliability that is required, and, if possible, appraise the scale of demand that would be required to make the scheme feasible. It is not necessary to know this with certainty to proceed, but if guidelines do exist, they should be articulated so that the number of variables can be reduced. Prepare a list of 5 or 6 demands (Q_D) or demand timeseries ($Q_{D(t)}$) that encapsulate the nature of demand that could be reasonably sought.

Step 4 – Define Scheme Operational Logic
The operational logic of the ASR scheme should reflect the scheme layout, infrastructure and pattern of demands that wish to be met. In this paper, logic as set out in Section 4 is used.

Step 5 – Modify Streamflow Timeseries to Reflect ASR Offtake Discharges $Q_{O(t)}$
Generate an “ASR Offtake” ($Q_{O(t)}$) timeseries by applying known or possible operational criteria. For example, where the maximum discharge (C_O) is the only limitation to the ASR Offtake discharges, these timeseries can be developed by applying Eqn (5) to the catchment streamflow timeseries. The values of C_O should be selected with respect to an understanding of any known real-world restrictions or precedents, such as required in catchment water allocation plans.

Step 6 – Run Simulations of Pre-Storage
Prepare a list of 5 or 6 possible pre-storage sizes (V_P) that range from obviously-too-small up to the largest tank that site constraints or budget would reasonably allow.

Set Q_D = C_I and V_A infinitely large and calculate the system reliability and annual yield for every combination of Q_D and V_P by solving equations (1) to (7). Setting $C_I = Q_D$ forces $Q_I = Q_E$, which means the aquifer is un-utilized. This is modeling a case where the pre-storage is the only storage offered by the scheme and hence is modeling releases from the prestorage (ie aquifer injections). Prepare plots of reliability versus demand and annual yield versus demand for each pre-storage size (these can be plotted as multiple series on a single chart).

Step 7 – Run Simulations of Scheme
Calculate the ASR system reliability and annual yield for each of the possible aquifer storage sizes listed in Step 5. Prepare plots as suitable to examine the characteristics of the system. Recommended plots include reliability versus demand, yield versus demand, storage volumes versus time, and yield versus storage volumes.

Step 8 – Undertake Iterations to Test Assumptions
Review the results and iterate until an appropriate range of useful aquifer sizes is represented. Examine the sensitivity of variables, and identify which variables may be limiting the scheme yields. Repeat analyses as required to examine sensitivity to other assumed parameters such as alternative aquifer recharge rates. Revise as appropriate. It may also be necessary to revise the range of demands that are being considered.

Step 9 – Provide Yield Assessment for Scheme
With consideration to the above analyses, prepare final plots which depict the expected yield from the scheme for a range of reasonable storage sizes and likely system characteristics.

4.4. Starting Points

The following guidance has been prepared to assist with choosing reasonable values for storage and demand. This guidance is not designed to support prescriptive selection of values, but rather to assist with selecting values that are within reasonable bounds.

Table2. Estimated Range of Detention Storages

	Diameter	Approximate Volume		Verification
	m	*kL*	*ML*	
Constructed Reservoirs. *Diameter to Height Ratio = 2*	1.5	1	-	Small Residential Rainwater Tank
	4	25	-	Large Residential Rainwater Tank
	7	130	-	Small Constructed Reservoir
	14	1,000	1	Olympic Pool
	20	3,000	3	Regional Supply Constructed Reservoir
	25	6,000	6	Large Constructed Reservoir
	35	20,000	20	Very Large Constructed Reservoir
Constructed Wetland. *Depth = 1m*	150	20,000	8	Very Small
	250	50,000	50	Small
	500	200,000	200	Small - Medium
	1,000	800,000	800	Medium
	2000	3,000,000	3,000	Medium - Large

Table 3. Estimated Range of ASR Aquifer Storages

Diameter	Change in Head Due to ASR Recharge or Abstractions	Approximate Aquifer Storage (ML)			
		Confined Aquifer With Specific Storage = 1x 10^{-5} $^{1}/_{m}$			Unconfined Aquifer with Specific Yield = 0.15
km	*m*	*10m thick*	*50m thick*	*100m thick*	
2	2	1	3	6	900
	5	2	8	20	2,000
	10	3	20	30	5,000
10	2	20	80	200	20,000
	5	40	200	400	60,000
	10	80	400	800	100,000
50	2	400	2,000	4,000	600,000
	5	1,000	5,000	10,000	1,000,000
	10	2,000	10,000	20,000	3,000,000

Table 4. Estimated Aquifer Recharge / Abtraction Rates

Bore	Guideline
Lower Yielding Bores	< 5 L/s per bore
Higher Yielding Bores	10 – 20 L/s per bore

In favourable circumstances, higher yields may be obtained

Table 5. Tools for Crude Estimation of Urban Demands

Item	Guidance	
Town Water Supply	500 L / capita / day	Accounts for all usage sectors in town
Residential Usage	250 L / resident / day	Accounts for residential usage per person
Separate Dwelling	650 L / dwelling / day	Assuming 2.6 persons per separate dwelling
Separate Dwelling Indoor	350 L / dwelling / day	
Separate Dwelling Outdoor	300 L / dwelling / day	

Demands vary with location. Figures are for the purpose of crude estimations and are indicative only.

5. EXAMPLES

Two examples are provided. The first is a case study in which periods of injection and harvesting are separated and closely defined, and streamflows in each defined period are regular. In this case, the aquifer storage volume is an effective indicator of system yield. In the second example, injection and harvesting occur simultaneously and streamflows are dynamic. In this case, the pre-storage has a greater impact on the scheme, and the aquifer storage is a poor indicator on yield.

5.1. ASR as a Seasonal Supply

A small town in tropical Queensland is experiencing regular water shortages during the dry season, which occurs annually from May to November. With population growth, it has been assessed that in 20 years time the town will experience a deficit of some 300 ML over each dry period.

The town is located adjacent to a seasonal stream, which experiences high flows approximately 6 months per year, from November to April. In addition, a high yielding confined basalt aquifer system is found near the town, but existing usages have accounted for all natural recharge to this system, and no further groundwater can be allocated to the town. Town planners wish to assess the option of charging the aquifer during the wet season with water taken from the seasonal stream and harvesting during the dry season. The goal of this ASR scheme was to meet dry season demands (hopefully up to 300 ML/a) in May to November at an annual average reliability of 95%.

Streamflow records were available from a local gauging station which had approximately 12 years of records. Environmental flow requirements stipulated that no abstractions could be undertaken when flows are less than 50 L/s. It was assessed that the ASR offtake would feature a 500 mm pipeline, capable of transferring 500 L/s (C_O) by gravity to the aquifer recharge location. Using these two criteria, a 12 year timeseries of daily ASR offtake discharges ($Q_{O(t)}$) was developed (i.e. the streamflow records were processed with low and high pass filters at 500 L/s and 50 L/s respectively).

A timeseries of “ASR demand” ($Q_{D(t)}$) was developed so that from May through to November, demands were directed from the ASR scheme, at all other times, demands from the ASR scheme were zero (town demands being met by an alternative source).

The pre-storage options included constructed reservoirs or wetlands, and a wide range of sizes was possible. The behaviour of the pre-storage was modeled for a wide range of sizes and maximum injection rates (C_I) from 10 L/s to 50 L/s. A plot of total injections over the wet season versus maximum injection rate was made, as shown in Figure 4. For the purposes of this example, $R_{\%}$ was taken as 100%.

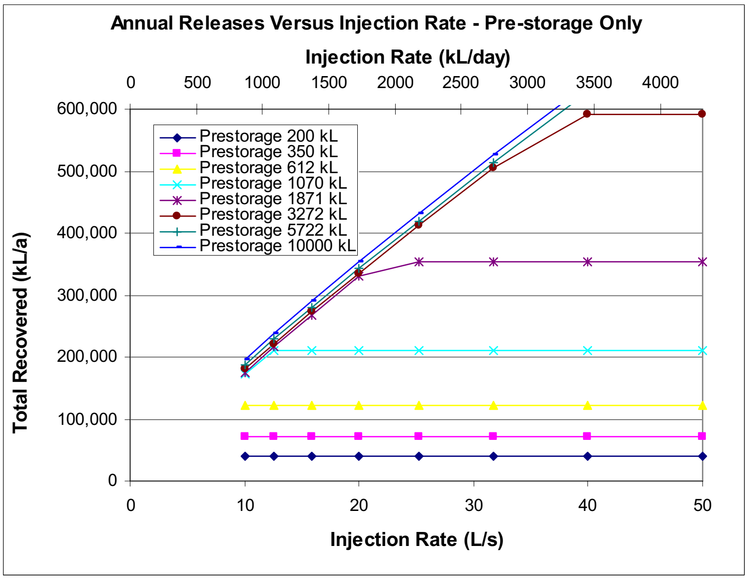


Figure 4 Examination of Pre-Storage – ASR Seasonal Supply Scheme

When the maximum injection rate (C_I) can deliver a volume of water, over one day, that is greater than the pre-storage volume (V_P), the pre-storage volume becomes the limiting factor. This is observed for all cases where the curve in Figure 4 is horizontal. There is little benefit gained from increasing the injection rate once this pre-storage limit has been reached. Where the curve is inclined, the system is limited by the aquifer recharge rate, and pre-storage can buffer more than one day's supply. In this case study, there is little benefit gained from buffering more than one days supply (ie inclined lines are closely spaced) – wet season flows are evidently reliable in delivering the required demands.

The equations were solved for various aquifer and pre-storage sizes and, for each combination, the annual yield at 95% reliability (over the dry season) was determined. The results are shown in Figure 5 for the case where maximum aquifer injection was 20 L/s.

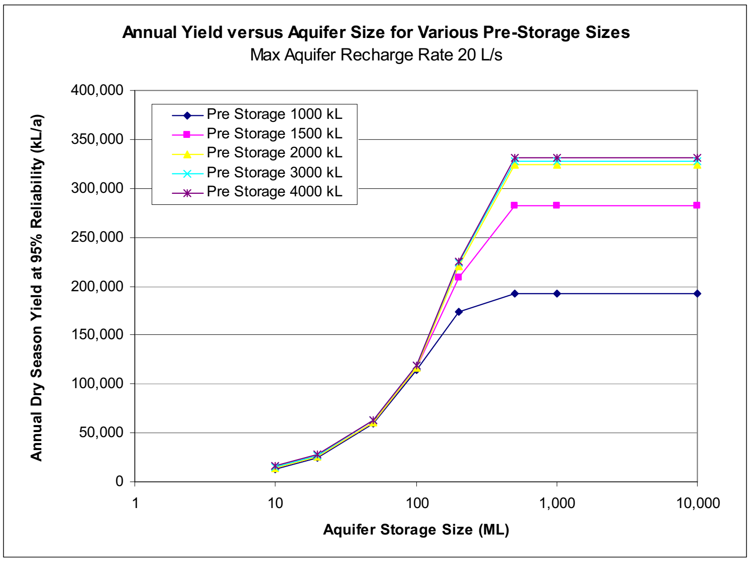


Figure 5 Examination of ASR System – ASR Seasonal Supply Scheme, C_I = 20 L/s

When the pre-storage size and aquifer access rate do not limit the scheme, the yield is linearly related to the aquifer storage size. A prestorage size of 1000 kL begins to limit the yield for aquifer sizes greater than 100 ML. A pre-storage size of 1500 kL limits the yield for aquifer sizes larger than approximately 300 ML. The aquifer access rate of 20 L/s then limits the scheme yield, and unless this rate is increased, there is no benefit for increasing the pre-storage size.

In this case study, the dynamic aspects of streamflow are diminished – during the dry season there is almost always zero flow, during the wet, although flows are dynamic, they are always in excess of demands or injection rates. Also, injection and abstraction times are distinct to each of these times. In this example then, the yield is closely approximated by the volume of water that can be successfully directed to storage during the wet season.

This analysis showed that the pre-storage only needed to be large enough hold one days 'injection', and construction of required pre-storage was therefore economically viable. The yield could not be deterministically assessed, but the analysis showed that the desired yield may be achievable depending on the aquifer characteristics, and hence further aquifer investigations were justified.

5.2. Small Urban Catchment ASR Scheme

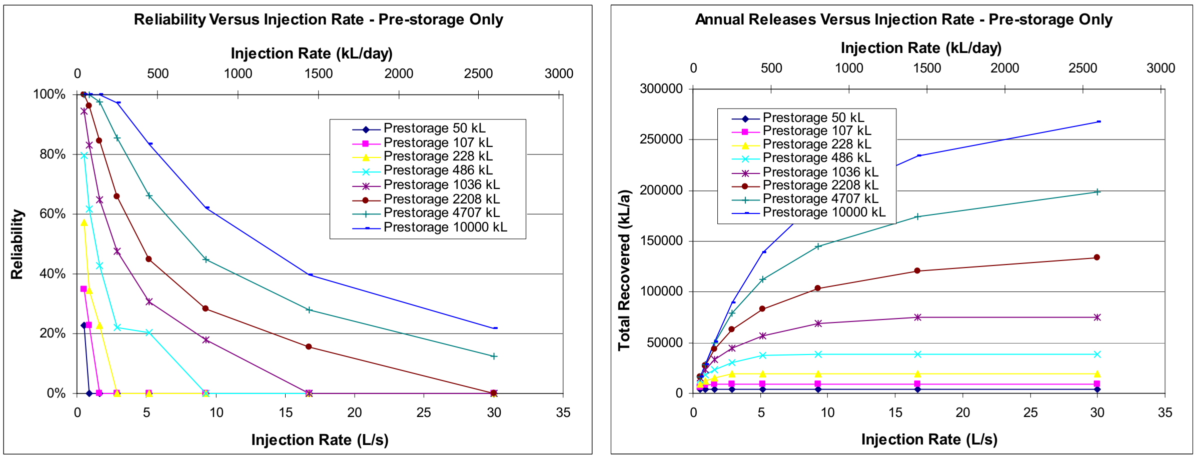
Works for construction of new civil infrastructure in South-East Queensland required relocation of a stormwater culvert. Site developers wished to assess opportunities for developing an ASR scheme to capture and reuse storm water from this culvert.

The catchment feeding the culvert was approximately 60 Ha in size, and was set in a suburban / semi rural environment. Catchment streamflows were modeled with daily timesteps using 80 years of historical rainfall data taken from a nearby gauging station. The stormwater outflows were irregular and highly dynamic, and while the total annual discharge was in the order of 300,000 to 500,000 kL/a, much of this was discharged in two or three significant events.

An area of approximately 1 Ha was available for development of ASR infrastructure, although an adjacent unused site of approximately 12 Ha appeared to be a possible location for a constructed wetland. 1000 kL was considered as an upper limit for a constructed storage tank, and 10,000 kL for a constructed wetland. It was considered plausible to route the entire storm water channel through the constructed wetland, hence no restriction (C_O) to the ASR inflows was introduced.

A brief desktop review of hydrogeological conditions was undertaken by referencing geological sheets and obtaining drilling records from a public database of registered bores. This showed banded sandy and gravelly clays extending to 40 metres depth, which were underlain by coal measures. Where recorded, bores typically displayed yields in the order of 1 L/s with the exception of one nearby bore which struck a confined 6m thick lense of gravel and recorded yields of 15 litres per second. In summary, most of the bores showed little promise, but this one bore indicated the possibility of higher transmissivity aquifers of limit extent. An operational injection rate of up to 10 L/s and aquifer storage of up to 10ML was considered possible real world estimates.

Simulations of the system yield and reliability for the case where no aquifer storage was utilized (ie pre-storage only) were undertaken. This was done for an optimistic range of injection rates. The results are shown in Figure 6a and 6b below.



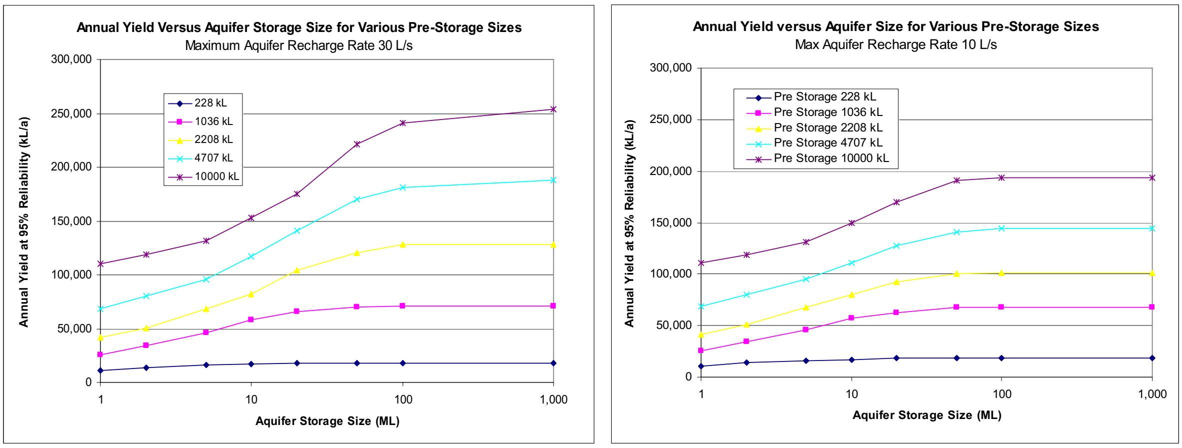
a) **b)**

Figure 6 Examination of Pre-Storage – Small Urban ASR Scheme

The size of pre-storage has a large effect on the quantity of water that can be captured and directed to aquifer storage. The yield curves (Figure 6b) are smoother than the previous example (Figure 4) as the streamflow dynamic range results in intermittent filling of the pre-storage – benefits are gained for providing more than a single day's storage. The range of storages displays a good 'spread' over the possible injection rates, suggesting an appropriate range of storage sizes has been chosen.

The equations were solved for the case where reliability of 95% was obtained, and results of annual yield versus aquifer storage for various pre-storage sizes were produced as shown in Figure 7. For this scheme, pre-storage size has a greater impact on yield at 95% reliability than aquifer storage size. An upper estimate of yield can be read off these Figures, depending on the pre-storage size the developer is prepared to construct, and assumed aquifer characteristics.

Yields from the scheme will not exceed 250 ML/a, even for the largest pre-storage (a constructed wetland), an aquifer storage of over 100 ML, and a high injection rate (30 L/s). However, the desktop hydrogeological study suggested aquifer storages of up to 10 ML and 10 L/s injection rate are more realistic upper estimates. In this regard, constructed pre-storages (up to 1000 kL) will offer yields less than 50 ML/a, and constructed wetland pre-storages up to 150 ML/a.



a) **b)**

Figure 7 Examination of System Yields – Small Urban ASR Scheme at 95% Reliability

With consideration to the local environment, the likely possible usage for harvested water was assessed to be secondary supply (ie non-potable) for outdoor usages at local residences. Using a figure of 350 Litres per household per day, it was considered the scheme may deliver demands of between 400 to 1200 houses (50 to 150 ML/a), if aquifer conditions were proved to be suitable.

The developer was advised of the relationship between pre-storage size and yield and an economic assessment of the costs for such pre-storages, and other key system components was made. These analyses showed that, even for the most favorable aquifer conditions, the cost of water from the ASR scheme would not be competitive against reticulated water costs. In addition, it was understood that aquifer conditions would most likely not be favorable. It was concluded not to pursue the scheme.

6. CONCLUSION

The yield of a water supply scheme is the discharge of water that can be consistently provided at a specified probability of failure. By offering storage, ASR schemes may be effective in buffering the natural variability of surface water systems, increasing the reliability or yield of water that is harvested from those surface water resources.

By examining the dynamics of these storage systems, and applying yield – reliability assessment techniques, it is possible to examine the scale of pre-storage and aquifer storage required for a proposed Aquifer Storage and Recovery scheme, and derive a useful examination of yield. This information can provide insights into the feasibility of the scheme prior to undertaking further field investigations. It can also show that it is not necessarily aquifer characteristics that control the overall feasibility or even the yield of the scheme. A methodology for undertaking such analyses has been presented in this paper and is considered useful for desktop level appraisals of ASR schemes at a level consistent with initial scoping studies or feasibility assessments.

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