TECHNICAL REPORT

FEASIBILITY STUDY & DESIGN FOR AN END OF CATCHMENT WETLAND TREATMENT SYSTEM – ELLEN BROOK

STAGE 1 REPORT

JUNE 2012

FOR
DEC ON BEHALF OF THE SWAN RIVER TRUST

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EXECUTIVE SUMMARY

In June 2006 the Australian Government's Coastal Catchment Initiative (CCI) identified the Swan Canning river system as a hotspot for water quality issues. Consequently, the CCI provided funding to the Swan River Trust (Trust) to develop the Swan Canning Water Quality Improvement Plan (SCWQIP). The SCWQIP, released in December 2009, provides a roadmap for reducing nitrogen and phosphorus nutrient levels within the Swan Canning catchment through Stream Quality Affecting Rivers and Estuaries (SQUARE) modelling and decision support tools.

The SCWQIP identifies the Ellen Brook catchment as the greatest nutrient contributor within the Swan Canning coastal catchments to the Swan Canning River system. Though Ellen Brook supplies only 14% of total annual flow, it delivers approximately 70 tonnes of total nitrogen (TN) and 10 tonnes of total phosphorus (TP) annually. This represents 28% of the TN and 39% of the TP delivered to the Swan Canning system from the coastal catchments. As such, the SCWQIP identifies the Ellen Brook catchment as a priority nutrient management area, and categorises it as being of "unacceptable water quality". To give some idea of the severity of the quality issues, the SCWQIP identified that load reductions of 69% TN and 79% TP are required to reduce the annual nutrient discharge to the maximum acceptable levels.

Prior to the development of the SCWQIP, a number of investigations and trials were conducted within Ellen Brook to address water quality issues. Preliminary investigations conducted by GHD in 2007 assisted in the development of a number of zeolite/laterite nutrient filter trial sites. These trials were implemented at a number of sites within Ellen Brook and its major and minor tributaries. Preliminary water quality monitoring of the nutrient filter indicated that the filter provides very little nutrient load reduction. SQUARE scenario modelling conducted after the construction of the nutrient filters reflected these monitoring results, estimating only minor load reductions of 0.01% for nitrogen and 0.21% for phosphorus.

In 2010 Kelsey *et al.* and the Department of Water (DoW 2010a) conducted SQUARE scenario modelling of a range of management actions within the Ellen Brook catchment. SQUARE modelling was used to compare current catchment TN and TP loads with the predicted loads following management interventions. Management interventions for the Ellen Brook catchment included: removal of point sources; removal of septic tanks; fertiliser efficiency; fertiliser action plans; wetland implementation and soil amendments. The scenarios which delivered the greatest nutrient load reductions included fertiliser action plans (4% TN and 22% TP reductions) and soil amendments (19% TP load reduction). Artificial wetlands delivered the next best load reduction of 2% TN and 4% TP. Whilst these scenarios are able to offer some nutrient load reductions, none of the individual or combinations of scenarios achieved the TN or TP reduction targets required by the SCWQIP. This highlighted the need to identify and develop new management measures and scenarios.

Recent advances by the CSIRO into the use of mining by-products as environmental amendments provided the potential to use a neutralised used acid (NUA) blend as a nutrient and dissolved organic carbon (DOC) removal media. Preliminary column trials and application of an NUA blend as a soil amendment to a turf farm has shown that NUA demonstrates high phosphorus retention capacity and good performance in terms of dissolved organic carbon (DOC) and nutrient removal from influent water. As such NUA was thought to be very promising as an environmental amendment for the attenuation of soils and waters containing high concentrations of labile P, inorganic and organic N species and DOC, such as Ellen Brook water.

Whilst the NUA blend presents promising nutrient removal capacity, a number of potential issues and uncertainties were identified in the column trials. These issues and uncertainties require resolution to facilitate large-scale application to the Ellen Brook project. Note, whether or not these are of concern will depend on how the media is applied (e.g. within the river system or off-line) and what the final blend of media is likely to be.

Key potential issues identified in the column trials include:

1. *Contaminants breakthrough* – reappearance of high levels of some contaminants such as DOC, NH3-N or even DON in the effluent treated water as a result of the reactive phase being spent in the system.
2. *Flows* - uncertainty regarding the performance of an NUA blend in a full-scale system with high and variable flows.
3. *Environmental impacts* – due to the potential release of Mn at levels that may cause an impact on Ellen Brook or Swan River downstream.
4. *Increase in salinity* – due to release of high levels of Ca, Mg and in particular SO4 from hydrated NUA. High salinity can have negative impacts on the freshwater river system. This may be particularly significant at the localised river discharge point during the summer period when flows are minimal and evaporation is very high.
5. *Sulfide generation* – release of high SO4 levels from NUA can, under anaerobic/anoxic conditions, result in sulfate reduction and generation of sulfide which in turn can cause toxicity to plant roots and aquatic organisms.
6. *Additional toxicity of NUA leachate* – it is possible that over the long life-time of the full scale system continuously exposed to high and potentially variable flows, NUA leachate may have some additional toxicological effects on the aquatic environment.

The NUA pilot study, an initiative between the Trust and CSIRO, is currently underway and will provide additional information and data critical to determine the issues and uncertainties with the in-situ application of NUA. As the results of this trial were not available at the time of this report, the scope of this feasibility study reflects data from the column and turf trials only.

Task two of this document presents an opportunities and constraints analysis for NUA and two sites identified by the Trust for the purpose of the feasibility study. This analysis informed the development of the design criteria, design approach and options development.

Task three presents three alternative NUA treatment system options developed for the purpose of this feasibility study. The first option presents a fully passive system that utilises offline wetlands and NUA trenches that intercept surface and groundwater. The second option presents a weir and pumped system, whereby flows contained within a series of weirs are actively pumped through an NUA treatment system. Wetlands located at the terminal end of the NUA system polish the NUA effluent. The third option combines the abovementioned passive and active NUA treatment systems, utilising a weir and pumped treatment system in combination with gravity fed NUA trenches.

The above options were developed with input from the Ellen Brook project working group (PWG, 24th August 2010 workshop).

INTRODUCTION

1.0 PROJECT BACKGROUND

In June 2006 the Australian Government's Coastal Catchment Initiative (CCI) identified the Swan Canning river system as a hotspot for water quality issues. Consequently, the CCI provided funding to the Swan River Trust (Trust) to develop the Swan Canning Water Quality Improvement Plan (SCWQIP). The SCWQIP, released in December 2009, provides a roadmap for reducing nitrogen and phosphorus nutrient levels within the Swan Canning catchment through Stream Quality Affective Rivers and Estuaries (SQUARE) modelling and decision support tools.

The SCWQIP identifies the Ellen Brook catchment as the greatest nutrient contributor within the Swan Canning coastal catchments to the Swan Canning River system. Though Ellen Brook supplies only 14% of total annual flow, it delivers approximately 70 tonnes of total nitrogen (TN) and 10 tonnes of total phosphorus (TP) annually. This represents 28% of the TN and 39% of the TP delivered to the Swan Canning system from the coastal catchments. As such, the SCWQIP identifies the Ellen Brook catchment as a priority nutrient management area, and categorises it as being of "unacceptable water quality". To give some idea of the severity of the quality issues, the SCWQIP identified that load reductions of 69% TN and 79% TP are required to reduce the annual nutrient discharge to the maximum acceptable levels.

Syrinx Environmental PL was engaged in July 2010 by the Department of Environment and Conservation (DEC) on behalf of the Trust to determine the overall feasibility of installing an end of catchment treatment system at two sites within Ellen Brook. The purpose of this treatment system is to provide nutrient load reductions prior to Ellen Brook discharging to the Swan River. Syrinx's services are split over two stages. The first stage of the project involves a desktop study looking at project background, literature/data review, site opportunities and constraints and the development of three conceptual design options. The second stage will focus on the most appropriate treatment materials (NUA blends), treatment components and sequence, final design elements, cost effectiveness analysis, life cycle costs and risk assessment.

The purpose of this document is to deliver the Stage 1 components.

2.0 AIMS AND TARGETS

Broad aims for the end of catchment treatment system encompass environmental, social and economical aspects. Aims were identified by Syrinx Environmental PL and reflect value identification within the SCWQIP and the Ellen Brook Water Quality Improvement Plan (WQIP)

(Trust, 2009b) in addition to aims presented by the Trust in the request for quotation (RFQ). These aims are listed below.

- Maximise water quality improvements within lower Ellen Brook and the Swan Canning river system;
- Minimise flood threat to infrastructure and existing land uses (agricultural and residential);
- Protection and enhancement of environmental values including environmental flows, hydrological cycles, biodiversity, ecosystems and habitats;
- Protection and enhancement of cultural and spiritual values: Community education; community involvement; European heritage and Aboriginal heritage; and
- Maximise economic efficiency.

A number of TN and TP reduction targets are applicable in the context of this project. The SCWQIP sets out the annual maximum acceptable load targets for the Ellen Brook catchment at 22 tonnes/year for TN (69% TN reduction) and 2.1 tonnes/year for TP (79% TP reduction). These targets should be viewed as the overarching reduction targets all management actions implemented within the catchment, with the end of catchment treatment system being part of a larger treatment train. Within the RFQ the Trust sets out the TN and TP load reduction targets for the end of catchment treatment system. These targets are identified below.

- A 30% TN load reduction and a target winter median discharge concentration of 1.0 mg/L by 2015;
- A 30% TP load reduction and a target winter median discharge concentration of 0.1 mg/L by 2015.

Identification of the ability for the end of catchment treatment system to meet these targets is discussed in the options development section of this feasibility study (section 10.0).

3.0 METHODOLOGY

This document has been structured in accordance with the scope provided in the Feasibility Study and Design for an End of Catchment Wetland Treatment System – Ellen Brook Request for Quote (RFQ). As such, the document has been structured into three main tasks as follows:

- <u>Introduction</u>
    - Project background

- Aims and Targets
- Methodology

- Task 1: Literature Review
  - Summary of catchment data and reports
  - Summary of Neutralised Used Acid (NUA) data and reports
- Task 2: Opportunities and Constraints
  - Site location
  - Opportunities and constraints matrix
  - Design implications
- Task 3: Options development
  - Identification of potential components
  - Configuration and placement of components
  - Development of three conceptual designs for consultation

TASK 1: LITERATURE REVIEW

A number of reports were provided by the Trust for the purpose of this literature review. An additional report developed by CSIRO (Barron *et al.* 2010) was added to the review by Syrinx Environmental. This was due to data gaps associated with the groundwater characteristics of the Ellen Brook catchment. A summary list of the reports and data provided by the Trust is shown in Table 1.

Table 1 Summary of Existing Documents

Reports and Discussion Papers			
Date	**Title**	**Author**	**Subject**
2008	Healthy Rivers Action Plan	Swan River Trust	Water Quality Improvement Plans
2008	Local Water Quality Improvement Plan Ellen Brook	EBICG & Trust	
Dec 2009	Swan Canning Water Quality Improvement Plan	Swan River Trust	
Feb 2010	Hydrological and nutrient modelling of the Swan-Canning coastal catchments	DoW	Hydrological and nutrient data and modelling
Feb 2010	Hydrological and nutrient modelling, Appendix A: Calibration Report	DoW	
Feb 2010	Hydrological and nutrient modelling, Appendix B: Modelling results for reporting subcatchments	DoW	
July 2010	Groundwater contribution to nutrient export from Ellen Brook catchment	CSIRO	
Nov 2007	Report for Selection of Drainage Improvement Sites and Nutrient Interventions in the Lower Ellen Brook Catchment	GHD	Scenario modelling & trials
Aug 2008	SSPND: The Support System for Phosphorus & Nitrogen Decisions, BMP Scenarios for Ellen Brook Catchment	Ecotones & Associates	
Jan 2010	Scenario modelling for local water quality improvement plans in selected catchments of the Swan-Canning Estuary	DoW	
June 2009	Charaterisation of Mining and Industrial By-Products with Potential for Use as Environmental Amendments	CSIRO	CSIRO Reports - NUA
June 2009	Best Management Practices: Investigation of Mineral-Based By-Products for the Attenuation of Nutrients and DOC in Surface Waters from the Swan Coastal Plain	CSIRO	
Aug 2009	A Review of Mining and Industrial By-Product Reuse as Environmental Amendments	CSIRO	
Dec 2009	Investigation of Trace Element and Radionuclide Mobility in amended Soils (Use of Neutralised Used Acid in Turf Farm Applications). Results from Bullsbrook Turf Farm Trial Extension, 2008-2009	CSIRO	
April 2010	Evaluation of Mining By-Products for the Removal of Nutrients and DOC from Ellen Brook Waters	CSIRO	

4.0 SUMMARY OF CATCHMENT DATA AND REPORTS

4.1 BACKGROUND

This literature review will summarise the Ellen Brook catchment characteristics, hydrological and nutrient modelling, water quality and quantity objectives and targets, scenario modelling and programs and trials. All data pertaining to water quantity and quality was summarised in the context of the SQUARE model presented in the SCWQIP. Confidence assessments on SQUARE outputs conducted by Kelsey *et al.* (2010) identified a high confidence for data utilised and generated for the Ellen Brook catchment.

4.2 CATCHMENT CHARACTERISTICS

The use of the model Stream Quality Affecting Rivers and Estuaries (SQUARE), developed by the Department of Water (DoW), enables the differentiation of 30 sub-catchments within the Swan Canning coastal catchment. The SCWQIP presents the extent of the Ellen Brook sub-catchment and identifies it as the largest of all Swan Canning coastal sub-catchments. The Ellen Brook catchment occupies an area of 716.4 km^2 (or 34% of the total Swan Canning coastal catchment area). The Ellen Brook catchment extends from the confluence of the Ellen Brook with the Swan River in the south, 50 km north and 15-20 km east to west.

Historically, the catchment was heavily vegetated and contained several pools, swamps and freshwater lagoons (Trust, 1997). European settlement has seen widespread clearing of native vegetation, with approximately 387.4 km^2 (54%) of area cleared for rural uses (Kelsey *et al.* 2010). Some remaining areas of vegetation have high conservation value, containing several threatened ecological communities, priority flora and the critically endangered western swamp tortoise.

Currently, the majority of the Ellen Brook Catchment is zoned as rural, with dominant land uses of cattle grazing, horse properties, poultry farming, hobby farms and vineyards (Kelsey *et al.* 2010; Trust 2009a). As many of the waterways within the catchment are in private ownership, the environmental values of the system extend to stock watering and irrigation, with only limited recreational amenity. The agricultural land uses, along with the large catchment area, have been attributed to the high levels of nutrient export from the catchment. The location and extent of each land use is shown in Figure 1.

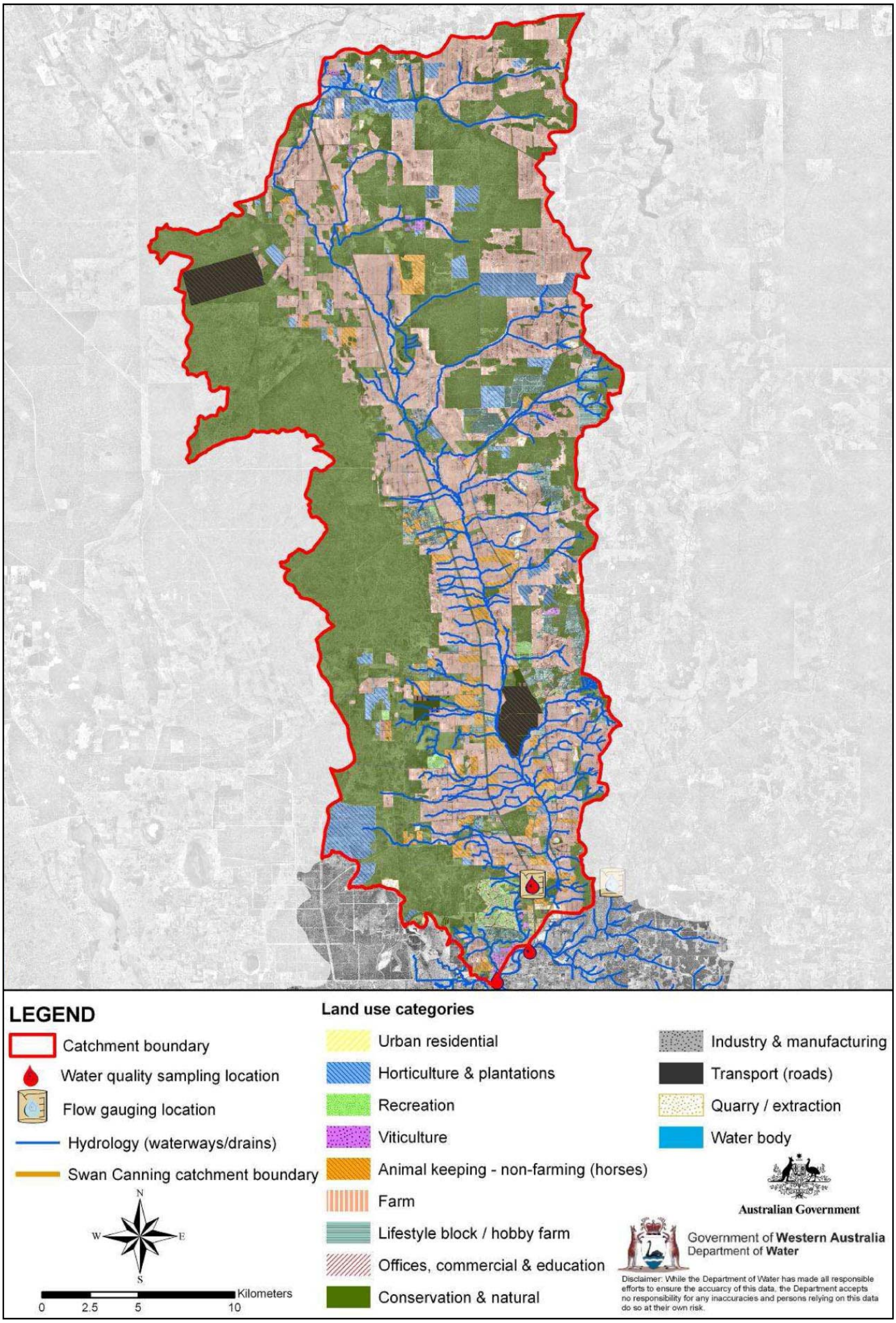


Figure 1 Ellen Brook Catchment land use map (from Trust 2009a)

In recent years areas in the south of the catchment have been undergoing urban development (Kelsey *et al.* 2010). This reflects the population growth of Perth and planned urban development within Ellen Brook. Approximately 17,770 new dwellings have and will be established in the area based on the Metropolitan Regional Scheme 2005 (Department of Planning, 2009). The impacts of future urban development on the water quality and quantity of Ellen Brook are discussed in section 4.5.

As discussed by Kelsey *et al.* (2010), the Ellen Brook catchment can be divided into three major geomorphic regions: the Darling Plateau to the east; the Dandaragan Plateau which covers the north eastern part of the catchment; and the Swan Coastal Plain which covers the western portion of the catchment (Kelsey *et al.* 2010; EBICG 2008). The soil-landscape within the catchment comprises Bassendean Sand, Pinjarra Zone and Dandaragan Plateau zone. The Aeolian Bassendean Sand and Alluvial Pinjarra Zone soil-landscapes are part of the Swan Coastal Plain region and generally have poor phosphorus retention indices (PRIs) resulting in the leaching of phosphorus from the soil throughout the catchment.

The Ellen Brook catchment experiences a Mediterranean climate with cool, wet winters from June to August and dry hot summers from December to March. Temperatures range from 17ºC to 29ºC in summer and <9º C to 18ºC in winter. Rainfall ranges between 820mm/yr in the south to 660mm/yr in the northern region of the catchment. The break of season is usually in April or May, and 90% of the rainfall occurs between May and October (EBICG 2008). Total pan evaporation is 1934mm/yr, with an average daily evaporation of 10.8mm in January to 1.8mm in June (EBICG 2008).

Recent hydrogeological investigations by Barron *et al.* (2010) identified the influence of groundwater recharge and discharge areas, sources of water (surface or ground) and areas of the catchment that contributed to the flow within the Ellen Brook. On an annual basis, baseflow accounts for (on average) 44% of stream discharge (baseflow is defined as flow of 20 L/sec and is derived from groundwater discharge and the slow drainage of water stored in local wetlands). The contribution of groundwater discharge to streamflow is significant in two areas: 80% of groundwater discharged to streams in the catchment occurs on the Dandaragan Plateau, with 5% of the catchment's groundwater discharge occurring downstream of the gauging station 616189 (Ellen Brook, Railway Parade) (Kelsey *et al.* 2010). The nutrient concentrations in baseflows are generally lower than during stormflows, however, shallow groundwater in areas of Bassendean Sand is likely to have high concentrations of phosphorus and organic nitrogen.

4.3 HYDROLOGICAL AND NUTRIENT DATA AND MODELLING

SQUARE modelling was developed by the Department of Water (DoW) under the CCI for conceptualisation and estimation of flows and nitrogen and phosphorus loads from each sub-catchment within the Swan Canning coastal catchment. The model's configuration, input data and calibration processes are described in detail by Kelsey *et al.* (2010). At its core, the model requires meteorological inputs (rainfall and evaporation), spatial inputs (soil and land-use attributes) and observed data for calibration (daily streamflow and nutrient sampling data). SQUARE modelling of the Swan Canning coastal catchments utilised rainfall data with a daily time step from 1970 to 2006. Gauging station 616189 was used for calibration of Ellen Brook results.

SQUARE modelling results for Ellen Brook average annual flows and nitrogen and phosphorus loads in addition to the resulting load reduction targets are presented in the SCWQIP (Trust 2009a) and supported by Kelsey *et al.* (2010).

SQUARE modelling of average annual flows, loads and delivery of nutrients was discussed by both by Kelsey *et al.* (2010) and the Trust (2009a). For the period 1997 to 2006 the average annual discharge from Ellen Brook was <u>26,750 ML</u>. Though this equates to only 14% of the total flow from Swan Canning coastal catchments, it contributes a disproportionately high loading of nutrients to the system, delivering on average <u>71.4 tonnes (28%) of the TN</u> and <u>10.04 tonnes (39%) of the TP</u> annually. The modelled winter median concentration for TN was 2.55 mg/L and TP was 0.45 mg/L.

If current climatic conditions prevail, planned urban development within the catchment is estimated to result in increases in nitrogen and phosphorus loads by 23 tonnes (24% increase) and 3.1 tonnes (29% increase) respectively. This assumes that the new developments have reticulated deep sewerage system and similar nutrient exports to existing urban areas (Kelsey *et al.* 2010). If the developments are unsewered then the potential increases are estimated to be three times greater (DoW 2010a).

Flow and seasonal delivery of TN and TP were assessed over an average year (1997) by Kelsey *et al.* (2010) and are shown in Figure 2, Figure 3 and Figure 4. As shown in the figures, nitrogen inputs from Ellen Brook reflect the flow input with May to September being the months with significant nitrogen inputs. Phosphorus inputs are small or negligible from November to April, with a majority of the inputs occurring in the wettest moths of August and September. Similar seasonal variations were provided in the Report Card – Ellen Brook (Trust 2007).

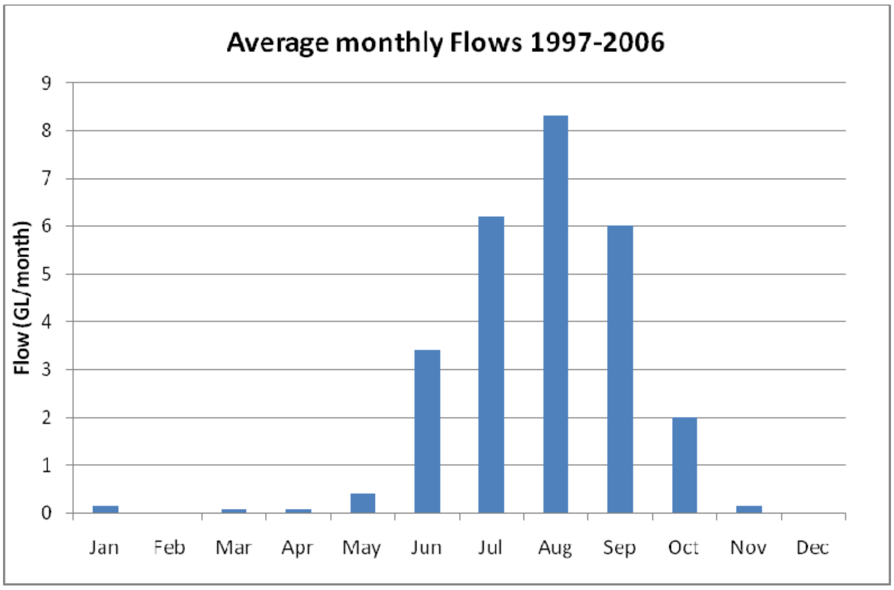


Figure 2 Average monthly flows from Ellen Brook from 1997 to 2006 (from Robb 2010, DoW 2010b)

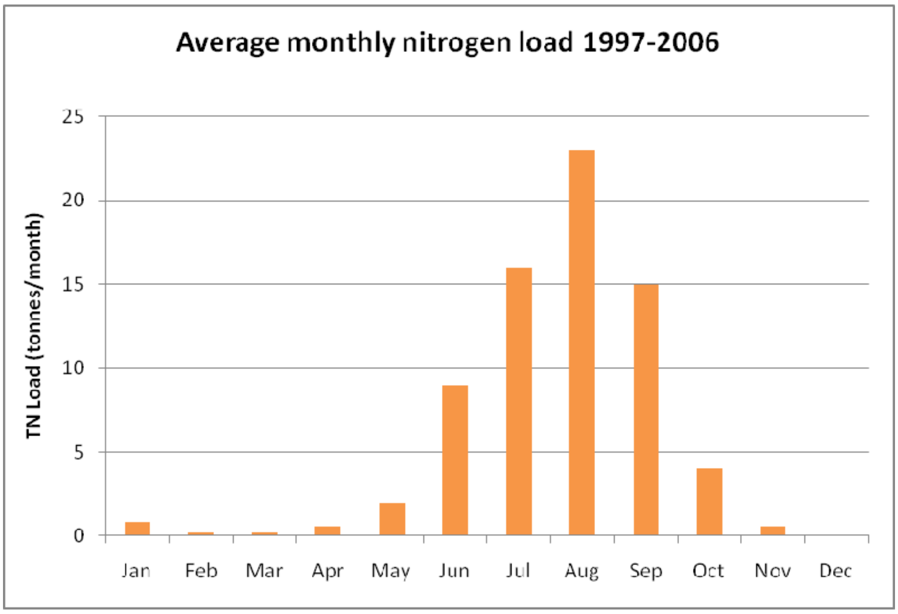


Figure 3 Average monthly nitrogen load from Ellen Brook from 1997 to 2006 (from Robb 2010)

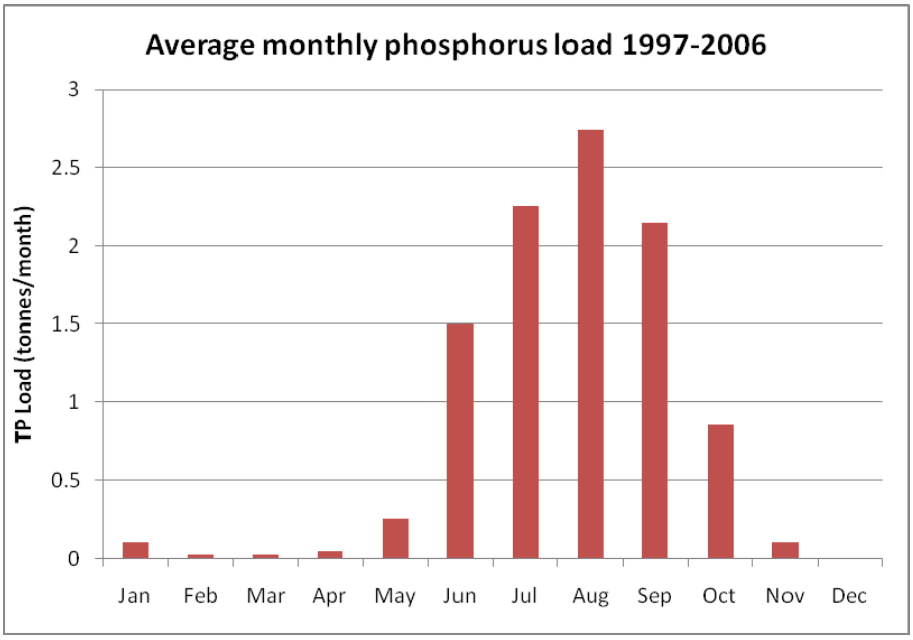


Figure 4 Average phosphorus loads from Ellen Brook from 1997 to 2006 (from Robb 2010)

Seasonal variation in nutrient inputs reflects the ephemeral nature of Ellen Brook with very little flow in Ellen Brook from January to April and October to December. This indicates that most of the Ellen Brook nutrient load is delivered in the large winter flows. Although the nutrient contributions from Ellen Brook during summer and autumn, considered to be the 'algal bloom season', are small, it is believed that phosphorus from the Ellen Brook winter inflows that is precipitated into the sediments of the upper Swan River is readily re-mobilised and available to fuel algal growth during summer and autumn (Kelsey *et al.* 2010).

As a result of the seasonal variation in nutrient levels, management actions that aim to treat low flows will have little impact on load reductions. To address nutrient inflows from Ellen Brook, management actions that decrease the nutrient inputs into the catchment or large scale engineering interventions that can treat large winter flows are required. Further details pertaining to these requirements are presented in the summary of the scenario modelling and trials (section 4.5).

SQUARE modelling encompasses nitrogen and phosphorus exports from different land uses as identified in section 4.2. Table 2 presents the land-use category and the corresponding average nitrogen and phosphorus exports as identified by Kelsey *et al.* (2010). Note that the land-uses do not include uncleared area as the measurement against "cleared area" is used to normalise the catchment export. This gives a better indication of the intensity of nutrient exports from developed land compared to normalisation by total catchment area alone (Trust 2009a). Cleared area within Ellen Brook equates to 387.4 km^2 (54%) and results in 1.84 kg/ha of nitrogen per cleared area and 0.26 kg/ha of phosphorus per cleared area.

Table 2 Land-use and corresponding average nitrogen and phosphorus exports (from Kelsey *et al.* 2010)

Nitrogen Sources			Phosphorus Sources		
Source	**Load (t/yr)**	**Load (%)**	**Source**	**Load (t/yr)**	**Load (%)**
Farm	6.52	64.9%	Horses	14	19.6%
Horses	1.92	19.1%	Farm	12.7	17.7%
Horticulture	0.89	8.9%	Horticulture	9.9	13.9%
Residential	0.27	2.7%	Residential	5.5	7.6%
Viticulture	0.18	1.8%	Septic	1.6	4.2%
Point Source	0.11	1.1%	Point Source	2.8	4.0%
Septic	0.11	1.1%	Viticulture	0.3	4.0%
Lifestyle Block	0.05	0.5%	Lifestyle Block	0.4	0.5%

Table 2 highlights that most nutrients come from rural land uses. The main source of nutrients for the period of 1997-2006 was farming, contributing 64.9% of nitrogen and 17.7% of phosphorus. Horse properties add a further 19.1% of nitrogen and 19.6% of phosphorus, followed by horticulture adding 8.9% and 13.9% respectively. Whilst the above data reflects information presented in the Local Water Quality Improvement Plan Ellen Brook Catchment (Trust 2009b), there appears to be differing source information presented in the DoW report (2010a). This may be due to the latter report undertaking revised land use mapping and including uncleared area within the source separation calculations.

Nutrient fractions for nitrogen (N) and phosphorus (P) are discussed in the Report Card – Ellen Brook (Trust, 2007). Almost all the N present in Ellen Brook is in the form of organic N, which consists of dissolved and particulate fractions (93%). Dissolved inorganic N (DIN) consisting of NH_4^+ and NO_x makes up the remaining N (7%). Most of the P present in Ellen Brook is soluble reactive P (SRP) (69%) with particulate P making up the remaining P (31%). These characteristics are consistent with water quality evaluations undertaken by GHD (GHD 2007).

4.4 OBJECTIVES & TARGETS

The Healthy Rivers Action Plan (HRAP) and SCWQIP set the water quality objectives, concentration targets and average annual maximum acceptable load targets for all catchments within the Swan Canning river system.

Median winter TN and TP concentration targets were first identified in the Trust's Swan-Canning Cleanup Program (SCCP). This program was then followed by the HRAP and concentration targets were refined for each sub catchment by Kelsey *et al.* (2010). Observed and target median TN and TP concentration applicable to Ellen Brook are shown in Table 3.

Table 3 Observed and target median TN and TP concentrations within Ellen Brook (from Kelsey *et al.* 2010)

	TN Concentration	TP Concentration
Observed median concentrations (1997 – 2006)	2.55 mg/L	0.45 mg/L
Long term target	1.0 mg/L	0.1 mg/L

The average annual maximum acceptable load targets are based on the ability of a stream to just meet its median concentration targets. This target was deduced from the SQUARE model by progressively reducing fertilisation inputs in the model until the estimated TN and TP concentrations in the streams reflected the median winter concentration targets shown in Table 3. As the effect of management actions are given in terms of load reductions, the SCWQIP presents the average annual load reduction targets (i.e. the average annual current load minus the average annual maximum acceptable load target). Current loads and load reduction targets applicable to Ellen Brook are identified in Table 4.

Table 4 TN and TP current loads, load reduction targets and maximum acceptable loads for the period 1997-2006 (from Kelsey *et al.* 2010; Trust 2009a)

	TN Loads	TP Loads
Current Load (1997 - 2006)	71 tonnes/year	10 tonnes/year
Maximum Acceptable load	22 tonnes/year	2.1 tonnes/year
Load reduction target	49 tonnes/year	7.9 tonnes/year
% Load reduction	69%	79%

The SCWQIP and Kelsey *et al.* (2010) identifies the Ellen Brook catchment as the greatest nutrient contributor of the Swan Canning coastal catchments. In total, it contributes 28% of TN and 39% of TP from the Swan Canning coastal catchments to the Swan Canning river system. This reflects the large catchment area and rural land uses. The Ellen Brook catchment is identified in the SCWQIP as having “unacceptable water quality” as both TN and TP load reductions are above the 45% threshold set in the SCWQIP. As such, Ellen Brook is categorised as a priority nutrient management area. Management measures are discussed further in section 4.5.

Environmental flow objectives have been identified in the SCWQIP for a range of environmental attributes including: hydrology; hydrodynamics; channel geomorphology; aquatic and riparian vegetation; fish assemblages; macroinvertebrates; waterbirds; riverine floodplains and water quality. The end of catchment treatment approach must consider the objectives to ensure the attributes are not detrimentally affected.

Environmental flow requirements are regulated by the DoW according to the sustainable diversion limit (SDL) approach. The SDL sets a conservative limit on the water extraction from surface water and groundwater that cannot be exceeded unless a detailed ecological water requirements (EWRs) investigation consistent with the *National Principals for Provision of Water to the Environment* (WRC 2000; ANZECC & ARMCANZ 2000) is completed. It is generally the case that water allocations within 'natural' tributaries, including Ellen Brook, have been exceeded and no more water may be diverted from these streams (Trust, 2009a). Discussion within the SCWQIP reveals that the development of a EWR is a lengthy and time consuming procedure, with just one Swan Canning sub-catchment having a complete EWR. It would seem likely that Ellen Brook, with its expansive catchment area and complicated hydrological regime, would not have a complete EWR in the near future and, as such, the current limit on extractions will remain for some time.

4.5 NUTRIENT MANAGEMENT MEASURES

Broad nutrient management measures and strategies for the Swan Canning coastal catchments are identified in the SCWQIP. Through the CCI, the Ellen Brook Catchment Management Plan is being updated and the Trust has developed the Ellen Brook WQIP (Trust 2009b). The purpose of the WQIP is to provide stakeholders with a mechanism to prioritise management recommendations for the Ellen Brook catchment.

Ten management strategies are recommended in the WQIP (Trust 2009a). Broadly, strategies encompass policy development, water quality monitoring, regulation and reduction of agricultural discharge, fertiliser education and management, nutrient intervention and improved drainage and full connection to deep sewerage. These strategies are presented as a treatment train approach, whereby management strategies are combined along a nutrient pathway from their source to reduce TN and TP export. The treatment train approach is advocated in the SCWQIP and supported by scenario modelling which identifies that no single treatment can reduce either the nitrogen or phosphorus load to achieve the maximum acceptable load for the catchment.

SQUARE scenario modelling, economic SSPND modelling and in-situ trials have been established to determine the effectiveness of select management strategies. These are summarised below. Reductions in TN and TP loads as a result of the management strategies will be accounted for through ongoing monitoring of Ellen Brook and annual reporting through the Healthy Rivers Program.

Scenario modelling aims to predict the impact of various management measures on TN and TP loads. In Ellen Brook, the SQUARE model is coupled with an economic model (SSPND) to estimate the nutrient removal capacity and cost effectiveness for a range of scenarios.

Additionally, qualitative assessments and economic investigations were conducted by GHD (2007) on a number of nutrient intervention options.

Scenario modelling utilising SQUARE has been conducted by Kelsey *et al.* (2010), the DoW (2010) and documented in the SCWQIP. SQUARE modelling encompassed a number of different scenarios selected by the CCI steering committee. Maximum acceptable loads and scenario modelling results for climate change and future urban development are shown in Table 5. For the purpose of scenario modelling, the flows and nutrient reductions are calculated at catchment equilibrium. The catchment equilibrium denotes the average TN and TP over a 10 year climate sequence that has stabilised (in this case, the climate sequence for the scenario modelling is the climate for the period 1997 to 2006 repeated six times until 2006). That is, the catchment is in equilibrium with respect to the new catchment land uses or management practices (Kelsey *et al.* 2010).

Table 5 Scenario modelling results (from Kelsey *et al.* 2010)

Scenarios	Flow		Total Nitrogen		Total Phosphorus	
	ML/yr	% change	tonnes/yr	% reduction	tonnes/yr	% reduction
Catchment equilibrium	25,400	-	92.8	-	10.55	-
Climate change B1	23,500	-7%	86	-7%	9.6	-9%
Climate change A2	12,200	-52%	73.2	-21%	5.22	-51%
Future urban (no soil amendment)	27,000	6%	115.4	24%	13.64	29%
Future urban (with soil amendment)	27,000	6%	115.4	24%	13.04	24%
Maximum load target	-	-	22	-69%	2.1	-79%

Table 5 highlights that both climate change scenarios B1 (optimistic) and A2 (worst case) result in flows reductions and subsequent reductions in nitrogen and phosphorus. Future urban growth will see the opposite, with flows, and nitrogen and phosphorus loads increasing.

Scenario modelling for management actions is presented in Table 6 and Table 7. Modelling results from both Kelsey *et al.* (2010) and DoW (2010) are presented below to allow for comparison.

Table 6 Average annual nitrogen loads for scenario modelling in Ellen Brook catchment (from Kelsey *et al.* 2010; DoW 2010a)

	Kelsey et al. (2010)			DoW (2010)		
Nitrogen scenarios	**Load** tonnes	**Load reduction** tonnes	%	**Load** tonnes	**Load reduction** tonnes	%
Equilibrium (2057-2066)	92.8	-	-	91	-	-
Point source removal	90	2.8	-1.50%	-	-	-
Septic tank removal	91.2	1.6	-2%	90.3	0.7	-1%
Urban fertiliser reduction (50%)	89	3.8	-4%	-	-	-
Urban fertiliser reduction (20%)	-	-	-	90	1	-1%
Artificial wetlands*	90.9	1.9	-2%	89.1	1.9	-2%
Zeolite nutrient filters	92.8	0	-0.01%	-	-	-

*Traditional wetland approach, no nutrient adsorbent materials incorporated

Table 7 Average annual phosphorus loads for scenario modelling in Ellen Brook catchment (from Kelsey *et al.* 2010; DoW 2010a)

	Kelsey et al. (2010)			DoW (2010)		
Phosphorus scenarios	**Load** tonnes	**Load reduction** tonnes	%	**Load** tonnes	**Load reduction** tonnes	%
Equilibrium (2057-2066)	10.55	-	-	10.4	-	-
Point source removal	10.4	0.15	-1.10%	-	-	-
Septic tank removal	10.04	0.51	-4%	10.3	0.1	-1%
Fertiliser action plan (urban	10.3	0.25	-3%	9.5	0.9	-9%
Fertiliser action plan (rural	8.3	2.25	-21%	7.9	2.6	-25%
Fertiliser action plan (both)	8.2	2.35	-22%	7.7	2.7	-26%
Urban fertiliser reduction (50%)	10.3	0.25	-2%	-	-	-
Soil amendments (urban only)	-	-	-	10	0.4	-4%
Soil amendments (rural only)	8.53	2.02	-19%	8.3	2.1	-20%
Artificial wetlands*	10.15	0.4	-4%	10	0.4	-4%
Zeolite/laterite nutrient filters	10.5	0.05	-0.21%	-	-	-

*Traditional wetland approach, no nutrient adsorbent materials incorporated

Results presented in Table 6 highlight that the largest TN load reductions are achieved by urban fertiliser reductions (50%) followed by septic tank removal and implementation of artificial wetlands. The largest reductions in TP loads are achieved by implementing a fertiliser action plans in rural areas followed by application of soil amendments to rural areas. Septic tank removal and artificial wetlands offer small TN removal whilst zeolite/laterite nutrient filters offer negligible nutrient removal. Similarly, implementation of urban management actions have only slight effects on TN and TP reductions due to the small areas attributed to urban development. SQUARE scenario modelling highlights that no individual management action, or combination of management actions, can reduce the nitrogen and phosphorus loads to meet the average annual maximum acceptable load targets set in the SCWQIP. However, due to the magnitudes of the loads delivered by the catchment to the Swan Canning river system, even a small decrease in load would benefit the health of the river system (DoW, 2010).

The SSPND model was developed by the Department of Agriculture and an economic assessment of management actions was conducted for the Ellen Brook by Ecotones and Associates (2008). The assessment looked at the economic efficiencies of a number of management actions including: riparian management; fertiliser management; perennial pastures; soil amendments; fertiliser reduction (urban areas); infill sewer connection and septic tank upgrade. Cost benefit analyses highlighted that most management actions were economically feasible over a 10 year timeframe (i.e., the costs were not substantial). High levels of riparian management and perennial pastures delivered the best TN and TP reductions, however, high capital costs resulted in an overall net cost of $3 to 6.5 million. Soil amendments and fertiliser management delivered the next highest TN and moderate TP reductions and were associated with highest benefits per kilogram of TP and TN removed. Sewer infill was associated with the highest capital costs of approximately $40 million and had limited TN and TP reductions. Similarly, residential fertiliser programs showed limited nutrient removal and high overall costs.

In 2007 GHD was appointed by the Trust to investigate the suitability of 50 sites of Government owned land in lower Ellen Brook for the implementation of nutrient intervention works. Preliminary practicality assessments and opportunities and constraints analyses resulted in a shortlist of 26 potential sites. Investigations into nutrient characteristics, removal efficiencies and economic feasibility were conducted for a range of nutrient intervention systems including: nutrient filters (zeolite/laterite); in-stream treatment donuts; constructed wetlands; in-stream treatment weir; aquatic vegetation beds; treatment media blankets and permeable reactive barriers. Assessment of the above systems by GHD resulted in the identification that most systems did little to treat the problematic winter flows. GHD recommendations were thus limited to a treatment train of sedimentation wetlands and laterite/zeolite filters. These systems appeared to offer the most cost effective approach to TN and TP reductions. Three trial sites for these systems were recommended including: construction of a nutrient filter and sedimentation wetland upstream of Brand Highway; retrofit of an Ecomax pond as a sedimentation wetland with a downstream nutrient filter; and construction of a nutrient filter and sedimentation wetland upstream of the Muchea North Drain. Section 4.6 discusses the results of these trial sites.

4.6 PROGRAMS AND TRIALS

A number of programs and trials have been established for the Ellen Brook catchment by various stakeholders.

The Department of Agriculture and Food (DAF) is managing a number of projects to identify the most appropriate management practices for nutrient efficiency and reduction. Additionally, the DAF have installed field trials in Ellen Brook to test the effectiveness of drain fencing, in-stream interception and the application of nutrient retentive material in and around drains (Trust 2009a).

The Trust and local councils have developed a number of nutrient intervention trial sites within Ellen Brook. These included the Brand Highway, Bingham Road Creek and Muchea North Drain. Designs for the Brand Highway nutrient filter were developed concurrently with GHD's report by the Shire of Chittering and the Trust. In 2009 the Brand Highway nutrient filter was constructed. The filter extends 45 m upstream from the Brand Highway Bridge and consists of cracked laterite and zeolite placed in a channel to a maximum depth of 1 m. Preliminary water quality monitoring of the filter indicates that the filter provides very little nutrient load reductions. Furthermore, scenario modelling conducted by Kelsey *et al.* (2010) estimated load reductions of 0.01% for nitrogen and 0.21% for phosphorus. It was felt that these structures were not appropriate for the Ellen Brook catchment due to their low TN and TP removal efficiencies at high flows (Department of Water, 2010).

The Ellen Brockman Integrated Catchment Group (EBICG) was involved in extensive riparian revegetation works within the Belhus Reserve, lower Ellen Brook, from 2003-2004. The Belhus Reserve Management Plan (EBICG, 2008) details the revegetation works in addition to providing future management targets and actions for the reserve.

5.0 NEUTRALISED USED ACID

SQUARE scenario modelling and nutrient filter trials have identified that no individual or combination of management actions are able to achieve the TN or TP reduction targets as required by the SCWQIP. Additional or alternative management actions are therefore required. Recent advances by the CSIRO into the use of mining by-products as environmental amendments has highlighted the potential to use neutralised used acid (NUA) (singularly or in combination with other amendments) as a nutrient and dissolved organic carbon (DOC) removal media. This section provides a literature review of current available CSIRO reports describing characteristics and performance efficiency on NUA (refer Table 1). Note, since NUA is proposed to form the basis of the soil amendment media for Ellen Brook, the review is focussed on this amendment, rather than the various blends which may ultimately be used at full-scale.

5.1 BACKGROUND TO CSIRO STUDIES

Removal of contaminants, in particular nutrients from natural and wastewaters and soils, is a key environmental management priority in Western Australia.

One of the most pressing environmental issues in WA is the quality of stormwater in coastal catchments such as the Swan Canning coastal catchment. Continuous changes in land use including urbanisation and intensive agriculture have resulted in the accumulation of a substantial amount of nutrients within this catchment. The presence of excess bioavailable nutrients as a result of these changes is a major factor leading to the eutrophication of these waters and the resultant degradation in water quality. Effective removal of nutrients and other contaminants from the catchment is pivotal to effective long-term management of the Swan-Canning Estuary.

The focus of CSIRO work in the past few years has been on assessing the feasibility of using mineral-based sorbents for removal of contaminants, with the specific aim of identifying by-product materials “fit for purpose” for specific environmental applications. More specifically, CSIRO have undertaken several studies aiming to characterise an optimal material for removal of high concentrations of organic nitrogen and phosphorus from stormwater, such as at Ellen Brook. The goal of these studies was to identify industrial by-product materials that have high nutrient removal performance and provide cost-effective nutrient removal. From these studies, NUA (neutralised used acid) was identified as a potential nutrient and DOC removal media.

The outcomes of this extensive research undertaken by CSIRO, including the results of NUA blend bench scale and turf field studies have been outlined in a series of research documents listed in Table 1. These documents describe the physical and chemical characteristics of different material blends and their performance in removing nutrients. Because a singular document summarising and comparing various NUA trials undertaken has not been compiled (as far as we are aware), the aim of this NUA review (in line with the feasibility study scope of works) is to collate and summarise CSIRO studies identified in Table 1 and distil key issues/factors relevant to the application of this media to Ellen Brook.

5.1.1 Review Context & Limitations

As previously stated, while the CSIRO studies included comprehensive analysis and performance trials of several mining by-products, the focus of this short review is limited as follows:

- Review of the physico-chemical characteristics and performance of NUA only.
- Review is limited to the information and experimental data contained within the CSIRO reports that were made available during Stage 1 of the Ellen Brook project (for a list of reviewed reports see Section 5.1.2.).

- The review is intended to assist in the optimisation of design parameters for full-scale application of the soil amendments, and thus draws out results and discussion points raised in the CSIRO reports that will affect design parameters.
- The potential issues or risks associated with NUA are evaluated assuming its use within a section of Ellen Brook (end-of catchment treatment facility), or off-line but with discharge of treated water to Ellen Brook. That is, Ellen Brook at the proposed treatment point is assumed to be the aquatic receiving environment, rather than a treatment zone.
- The management of potential contaminants of concern by dilution (which is valid in an off-line system where water is added at a constant pumped rate to the NUA blend) is not assessed, since the intent is to review the soil amendment properties rather than a particular design solution. Moreover, this stage of the study requires the development of several design options, including within-stream options, and unless this section of Ellen Brook is reclassified as a mixing zone, then it is assumed that the current aquatic water quality standards apply.
- The extent to which the mass properties of the NUA generate output concentrations of potential contaminants of concern is dependent on a range of factors, including the flow rate of the influent. Given the hydraulic properties of the final NUA blend likely to be used in a full-scale design is not yet known, the extent to which ‘dilution’ through a treatment ‘unit’ may assist in limiting outlet concentrations is unknown and therefore not assumed in this review.

It is acknowledged that a blend of NUA with other absorbents, rather than NUA alone, is likely to be the preferred solution for full-scale application, i.e. the most ‘fit-for-purpose’ environmental amendment to be used in the Ellen Brook project. Therefore, the actual type and extent of risk or impact will be significantly influenced by the final media type, the dilution versus material mass of NUA/NUA blend, the extent to which the NUA is used ‘off-line’ vs ‘on-line’, and the relative impact of load vs concentration on the aquatic ecosystem.

5.1.2 Key Relevant Studies

Four key CSIRO studies were reviewed given their relevance to the Ellen Brook project.

Study 1: *Best management practices: investigation of mineral-based by-products for the attenuation of nutrients and DOC in surface waters from the Swan Coastal Plain* (Wendling *et al* 2009a).

This was the initial small-scale column laboratory trial in which different low-cost by-product materials were assessed in terms of their ability and efficiency to deal with nutrients and organic carbon in urban drainage waters. Low-cost materials incorporated into the testing program included the following:

- Clay minerals (vermiculite, attapulgite).
- Industrial by-products (NUA , red mud; red sand; carbonated red mud; steelmaking by-product; fly ash; calcined magnesia; lime-based groundwater treatment residues).
- Industrial materials (limestone, granite, greenstone, laterite).
- Carbonised wood products (granular activated carbon).

Performance indicators included nutrient and organic carbon uptake capacity, transformations and stabilisation. Materials were also assessed in terms of their additional benefits of reducing the environmental footprint of mining and mineral processing industries.

This study identified several low-cost mineral-based materials for potential use in water treatment schemes, in particular a heavy minerals processing residue, neutralised used acid (NUA). The study concluded the following:

> *In the specific context of Ellen Brook or other DOC, DON and inorganic P-enriched waters on the Swan Coastal Plain, a combination of materials, specifically NUA and one or more of calcined magnesia or granular activated carbon, could be used for broad spectrum nutrient removal in applications such as drain liners or constructed wetlands subject to optimisation of design parameters.*

Study 2: *Characterisation of mining and industrial by-products with potential for use as environmental amendments* (Wendling *et al* 2009b).

This study included detailed physical, mineralogical, chemical, radiological and toxicological characterisation of several mineral-based by-products, and provided information necessary to assess the potential suitability of each material for future use.

The materials examined in this study included:

- NUA - a heavy minerals processing residue (neutralised used acid).
- Steelmaking by-product.
- By-products generated during Bayer process alumina production and their derivatives (red mud, red sand, and reduced red sand).
- Lime- and $CaCO_3$-based residues from metropolitan groundwater treatment plants.

- Fly ash – a by-product of coal-based energy production.
- Other materials including laterite, calcined magnesia, and a carbonised wood product (granular activated carbon).

This study concluded that a number of industrial by-products readily available in WA possess characteristics which make them suitable as soil or surface water amendments, including the heavy minerals processing residue, neutralised used acid (NUA).

Study 3: *Evaluation of Mining By-Products for Removal of Nutrients and DOC from Ellen Brook Water* (Wendling *et al* 2010).

Study 3 was, in effect, a continuation and progression of Study 1, with the aim of evaluating the selection of mineral-based materials for the removal of high concentrations of DOC, organic N and P from Ellen Brook water. The three materials selected for use in this column trial were NUA, calcined magnesia (MgO), and a steelmaking by-product (SS). Again, these materials were assessed for their capacity to uptake nutrients and DOC from inflow Ellen Brook water.

Results of this column study 3 indicated that NUA (and mixtures of NUA/steelmaking by-product and NUA/calcined magnesia) have significant potential for nutrient and DOC attenuation in environmental applications. Although all three materials/by-product mixtures demonstrated high removal efficiency, the <u>NUA was found to be the most suitable for use as a water filtration media</u> in the Ellen Brook catchment, due to the environmentally acceptable pH of ~ 6.0-8.0 observed for NUA column effluents.

Study 4: *Investigation of Trace Element and Radionuclide Mobility in amended Soils (Use of Neutralised Used Acid in Turf Farm Applications). Results from the Bullsbrook Turf Farm Trial Extension, 2008-2009.* (Douglas *et al* 2009).

This field trial conducted in the period 2008-2009 was an extension of the original 307-day field trial 1 (undertaken between 2005 and 2008) and involved applying NUA (from Iluka, Capel) to untreated control soils at the Bullsbrook Turf Farm in Bullsbrook, WA (Douglas *et al.*, 2008). The aim of both of these trials was to investigate the efficacy of NUA as a turf farm soil amendment under a modified fertilization regime. NUA was incorporated into the top 15 cm of soil on a 5% basis (w/w) to mitigate off-site transport of applied nutrients at the Bullsbrook Turf Farm.

This turf farm field trial provided validation of the performance of NUA at a field scale, and has highlighted the high performance of NUA in terms of P and DOC sorption.

5.1.3 Key Study Findings

Together, results from these CSIRO studies demonstrated high P retention capacity of NUA, and good performance in terms of DOC and nutrient removal from influent water. As such NUA was thought to be very promising as an environmental amendment for the attenuation of soils and waters containing high concentrations of labile P, inorganic and organic N species and DOC, such as Ellen Brook water.

In addition to its performance, some of the key other benefits of NUA, as outlined by CSIRO, are:

- It is a low-value, mineral-based by-product.
- It is generated in large quantities in Western Australia and hence is widely available.
- Its use can help reduce the environmental footprint of their respective mining and mineral processing industries.

Results of above described studies relevant to NUA, including NUA characteristics and performance and potential issues associated with the use of NUA only, are described in sections below.

5.2 NUA CHARACTERISTICS SUMMARY

For the purpose of characterisation and evaluation of various by-products, including NUA CSIRO adopted a five Phase scheme approach, which includes the following steps: i) identification, sourcing and chemico-physical characterisation of products (Phase I), ii) column trials (Phase 2), iii) leachate toxicity testing (Phase III), iv) pre-commercial field trials to establish the product efficacy, applicability and cost-benefit, and v) regulatory approval process.

Studies 1-4 briefly described in Section 5.1.2 outline results of the first three Phases of NUA characterisation process. These results are summarised in individual sections below.

5.2.1 Production & Composition

NUA is a by-product of mineral sand processing and production of synthetic rutile (TiO_2). The mineral sands are separated physically into ilmenite ($FeTiO_3$), rutile (TiO_2) and zircon (ZrO_2). The low value ilmenite is upgraded to synthetic rutile by adding sulfuric acid to leach impurities from the reduced ilmenite. The used acid from the leach is neutralised with lime to produce a gypsum-based solid residue containing Fe and Mn, called NUA.

The main chemical reaction involved in the generation of NUA is:

$$2Fe^{3+} + 3SO_4^{2-} + 3CaO + 3H_2O \rightarrow 2FeOOH + 3CaSO_4 \cdot 2H_2O$$

Significant Mn present within the system also co-precipitates upon neutralisation.

As a part of Phase I of product characterisation scheme, a series of physico-chemical analyses of NUA was undertaken by CSIRO, including analysis of mineralogical composition by XRD (quantitative X-ray diffraction), characterisation of major and trace element composition by XRF (X-ray fluorescence), and radioactivity analysis.

Powder XRD analysis undertaken by CSIRO showed that the main mineral phase of NUA comprises gypsum ($CaSO_4 \cdot 2H_2O$) with minor quantities of magnetite (Fe_3O_4) and quartz (SiO_2). If partially hydrated, bassanite ($CaSO_4 \cdot 0.5H_2O$) may also occur while amorphous Fe and Mn oxides/oxyhydroxides may also be present.

Based on X-ray fluorescence (XRF), the six major elements in NUA are Fe_2O_3, CaO, SO_3 and to a lesser extent MnO, TiO_2 and SiO_2 (Wendling *et al* 2009b).

5.2.2 Physical Characteristics

The NUA has the appearance of a dark brown loamy soil. The particle size varies between 500-1000 µm to <63 µm with most particles being <63 µm in mean particle diameter (Wendling *et al* 2009b).

Table 8 NUA particle size distribution by sieve analysis (from Wendling *et al* 2009b).

SIZE FRACTION (µm)	NUA COMPOSITION (%)
> 1000	0
500 - 1000	1.21
355 - 500	8.38
250 - 355	7.77
180 - 250	5.13
125 - 180	5.09
90 - 125	4.96
63 - 90	10.17
< 63	57.29

The mean bulk density of NUA is found to be ~ 0.87 g cm-1; porosity is 0.59 (see Table 9).

Table 9 NUA porosity, bulk density and saturated hydraulic conductivity (from Wendling *et al* 2009b).

PARAMETER	NUA
Porosity by Br - breakthrough	0.59
Bulk Density by measuring cylinder (g/cm^3)	0.87
Bulk Density by gravimetric measurments (g/cm^3)	0.81
Saturated hydraulic conductivity by head preassure differential (cm/min)	0.54

NUA has a moderately high EC – 2.54 mS cm^{-1}.

5.2.3 Radiological Analyses

The calculated absorbed dose rate (D) for NUA was 263 nGy h^{-1}. This radioactivity is greater than the UNSCEAR guideline D of 11-54 nGy h^{-1}, but it is comparable to the radioactivity of Darling Scarp soils (35 to 378 nGy h^{-1}, average 195 nGy h^{-1}).

It has been suggested that dilution of NUA might be needed to improve suitability for environmental application, dependent on radionuclide speciation and mobility (Wendling *et al* 2009a).

5.2.4 Ecotoxicity of NUA

As a part of the Phase III of product characterisation process, NUA was tested for its ecotoxicity. In other words, a serious of leachate toxicity tests were undertaken in order to evaluate possible effects of the exposure of sensitive biota to NUA in field applications.

The NUA leachate used for ecotoxicological tests was prepared by mixing 50 g of powdered NUA with 1 L of synthetic softwater in 1 L LDPE Nalgene® bottles and was mixed by tumbling end-over-end at $30^{\pm}2$ rpm for 18 hours. Leachate was than centrifuged for 7 min at 2500 rpm and filtered through acid-washed (10% HNO_3) 0.45 µm membrane filters prior to toxicity testing (Wendling et al 2009b).

Trace elements that displayed enrichment (≥2 times) in the NUA leachate when compared to the softwater control (method blank) include Ba, Ca, Cl, Cr, F, K, Mg, N (primarily as NO_x-N), Na, Rb, S, Si, Sr and U .

Results of ecotoxicological testing of NUA were:

- NUA leachate was <u>not toxic</u> to *Ceriodaphnia dubia* (crustacea) using 48-hour acute cladoceran immobilisation toxicity. Toxicity is expressed as the concentration of sample leachate that causes a 50% reduction in cladoceran mobility (EC_{50}). Test results also indicated the lowest observable effect (LOEC) and no observable effect

(NOEC) concentrations. The EC_{50} and LOEC values were both >100%, and the no NOEC value was 100%.

- NUA leachate was not toxic to *Vibrio fischeri (luminescent bacteria)* in Microtox® tests. This test detects and measures inhibition of cellular activity (toxicity) which results in a decreased rate of respiration and a corresponding decrease in the rate of luminescence. The more toxic the sample, the greater the percent light loss from the test suspension of luminescent bacteria.

- NUA leachate caused inhibition of *Chlorella* sp.12 growth rate in 72-hour chronic algal growth rate toxicity test. At both 33% and 100% concentrations of NUA leachate, algal growth was significantly less than the method blank. The NOEC value for algal growth inhibition in NUA leachate was 11% and the LOEC value was 33%.

5.3 EXPERIMENTAL RESULTS & CONCLUSIONS

5.3.1 NUA Performance in Column Trial Experiments with Ellen Brook Water

Experimental Design

Two column trials were conducted by CSIRO to examine the capacity of different mineral-based sorbent materials to remove key contaminants from Ellen Brook:

Trial 1 – testing of twenty-five mineral-based sorbents or mixtures of sorbents, including NUA (Wendling *et al* 2009a).

Trial 2 - testing of NUA, calcined magnesia (MgO), and a steelmaking by product (SS) (Wendling *et al* 2010).

The objective of both trials was to evaluate mixtures of mineral-based materials for the removal of DOC, dissolved organic N (DON) and P from Ellen Brook water.

A summary of the experimental design for both of these trials (for NUA only) is given in Table 10.

In both experiments, NUA was mixed with non-sorptive Bassendean Sand, and columns with Bassendean Sand were also included as a reference. Ellen Brook water was passed through the columns with influent and effluents sampled and analysed for a range of water pollutants.

Geochemical calculations (using PHREEQC) were also undertaken as part of Trial 2 to estimate the saturation index of a suite of minerals, in particular, those of Al, Fe, Mn and Ca minerals.

Table 10 Column trials experimental setup - Trial 1 (June 2009) & Trial 2 (April 2010)

	TRIAL 1 June 2009	TRIAL 2 July 2010
Colum dimensions	1.0 m long, 2.2 cm ID	1.0 m long, 15 cm ID
Colum volume	380 cm^3 (0.38 m^3)	17.7 L
Column design	NUA is contained in a 50% mixture with Bassendean Sand in the middle third (33%) of the column. The top and bottom third of all experimental columns was comprised entirely of Bassendean Sand The NUA is ~ 17% (v/v) of total column. The effluent results relate to the total column.	NUA is contained in a 50% (v/v) mixture with Bassendean Sand in the middle 80% (80 cm) of the column. The top and bottom 10% (10 cm) of all experimental columns was comprised entirely of Bassendean Sand The NUA is 40% (v/v) of total column. The effluent results relate to the total column.
Total NUA mass	107 g	5.65 kg
Flow	0.2 mL/min	1 mL/ min
Water source	65/35 ratio of Ellen Brook to Southern River waterspiked with 100 µg/L P in the form of sodium phosphate ($NaH_2PO_4 \cdot 2H_2O$).	Ellen Brook water - from different locations or from other high-DOC sites on the Swan Coastal Plain when Ellen Brook water was unavailable
Exp duration	180 days	373 days

NUA Performance for DOC & Nutrients –Summary of Column Trial Results

A summary of NUA performance in terms of DOC and nutrient removal from influent Ellen Brook water from both column trials is given in Table 11. Note that the figures presented in Table 11 are relative to the Bassendean sand control.

Table 11 Summary of NUA performance in terms of DOC and nutrient removal - Trial 1 & Trial 2.

	% ANALYTE REMOVED		
	TRIAL 1		TRIAL 2
	after 60 days	after 180 days	after 373 days
NOx-N	88	79	-52
NH_3-N	81	77	57
DON	35	27	73
TN	65	45	61
PO_4-P	89	96	>99
TP	87	96	>99
DOC	62	39	80

Dissolved Organic Carbon: NUA showed good DOC retention capacity, with ~ 40% (Trial 1) and 80% (Trial 2) of DOC being removed from inlet Ellen Brook water, as compared to the Bassendean Sand reference column. In Trial 1 breakthrough of DOC in column eluents was observed following approximately 150 days of column operation, indicating a DOC sorption capacity of approximately 7.3 g/kg of NUA.

Phosphorus: In both trials NUA was shown to have a very high P retention capacity demonstrated as a high efficiency in the removal of PO_4-P and TP from influent water. Compared to the Bassendean Sand reference column, the NUA column achieved between 95% (Trial 1) and 99% (Trial 2) reduction in PO_4-P and TP concentrations in influent waters.

The uptake capacity of NUA for PO4-P or TP was not reached during the course of either experiment.

Nitrogen: The NUA demonstrated good capacity for N removal in both trials, however there was a marked difference in terms of removal of different N species as well as variation in total performance between two trials.

- *DON:* NUA showed good capacity for DON removal - ~ 30% (Trial 1) to 70% (Trial 2) of DON was removed in NUA columns. Reduction in DON observed in NUA column effluent was considered likely to be primarily due to the retention of dissolved organic matter, and hence DON, within the solid matrix.
- *NH_3-N*: NUA showed good capacity for NH3-N removal, but removal % varied between the two trials with greater removal observed in Trial 1 (77% Trial 1 vs 57% Trial 2).

Note, in Trial 1 breakthrough of NH3-N was observed following 78 days column operation.

- *NO_x-N:* In Trial 1 NUA achieved high removal of NOx-N (~ 80%). However in Trial 2 the NUA was shown to be less effective for the attenuation of inorganic N species than for DON. A net increase in NOx-N was observed in NUA column effluent, part of which may be attributable to transformation of N previously associated as DON.

The pattern of N and P removal in NUA columns creates a shift in nutrient limitation resulting in potential P-limitation in effluent water. Both the reduction in the overall nutrient concentrations and the P-limitation have important implications for eutrophication management as they can limit total algal biomass and promote a species shift away from potentially toxic N-fixing algal species (Wendling et al 2010).

The additional findings of the CSIRO trials which are important for the Ellen Brook project (i.e. will impact on the design of treatment system) relate to the performance of the Bassendean Sand, and can be summarised as follows:

- Bassendean Sand exhibited no sorptive capacity for DOC.
- Bassendean Sand reference column effluents showed a net increase in all nutrients except NOx-N. The observed reduction in NOx-N in column effluents is likely due to a combination of microbially-mediated mineralisation of particulate organic matter and denitrification.

Results of Geochemical Modelling

Throughout the trial, the saturation indices of Al, Fe, Mn, CO_3, SO_4 and PO_4 minerals in NUA columns remained similar with few changes observed between under- and oversaturation.

Geochemical modelling indicated that the effluent geochemistry of the NUA columns was dominated by near equilibrium saturation of ferrihydrite (Fe) and gypsum/anhydrite (Ca-SO_4) throughout most of the trial.

The three manganese minerals (manganite, rhodochrosite and pyrolusite) as well as calcium-bearing minerals (calcite ($CaCO_3$), dolomite ($CaMg(CO_3)_2$) and hydroxyapatite ($Ca_5(PO_4)_3(OH)$)) were undersaturated to varying degrees during the NUA column trial.

Iron minerals (hematite, goethite, schwertmannite and K-jarosite) exceeded saturation throughout the trial.

5.3.2 NUA Performance in Turf Field Trial

Experimental Design

The extended 2008-2009 field trial ran for 260 days (~nine months), bringing the cumulative monitoring of the Bullsbrook Turf Farm field trial site to ~4.3 years. Following the completion of the original Bullsbrook Turf Farm field trial, control and NUA amended experimental plots were further subdivided, resulting in two (2) control and two (2) NUA-amended experimental plots as follows:

- NUA amended - fertilised
- NUA amended – unfertilised
- Control fertilised
- Control – unfertilised

NUA amended plots had NUA incorporated into the top 15 cm of soil on a 5% basis (w/w). Both fertilised plots (the control and NUA-amended plots) received normal fertiliser applications. The alternate control and NUA amended plots did not receive any additional fertiliser for the duration of the trial. A local groundwater source was used for irrigation (composition not provided in this report); this groundwater apparently had substantially higher nutrient and lower DOC concentrations than the Ellen Brook water used in column experiments.

A range of analysis/monitoring was undertaken for all four plots, including: i) collection and analysis of lysimeter leachates for pH, EC, major and trace elements (X-ray fluorescence (XRF) analysis), nutrients and solute flux; ii) analysis of soil moisture profiles; iii) analysis of TN, TP and carbon in soil profiles and determination of phosphorus retention index (PRI); iv) assessment of turf regrowth; v) determination of leaf biomass and leaf nutrient chemistry.

NUA Performance–Summary of Turf Field Trial

Leachate flux: The total lysimeter flux (and hence flux to groundwater) was found to be consistently higher in the control sites compared to the NUA-amended sites. In general, the leachate flux in control sites was 1.5 – 5 times greater compared to the NUA-amended area.

Nutrients: Based on the lysimeter geochemistry, NUA amended sites (both fertilised and un-fertilised) had lower fluxes of nutrients to the groundwater compared to non-amended (control) sites.

- *Phosphorus*: In turf farm field trials the mean PO4-P fluxes to shallow groundwater were reduced by ~97% over approximately 4 years.

The concentration of P retained in the upper 15 cm of the soil profile in the NUA amended sites was approximately three times that of either of the control fertilised or control unfertilised sites. Below this upper 15 cm level, soil P concentrations were similarly low for all four sites irrespective of the presence of NUA.

Estimation of Phosphorus Retention Index (PRI) showed that surface soils to a depth of 5 cm had a PRI of 4-5 while deeper soils to 45 cm depth had a PRI typically of 1-2. Immediately after addition of NUA, the NUA amended soil had a nominal PRI of ~25 at 5 cm depth and ~6 at 15 cm depth, while three years later the PRI had reduced to ~13 and ~2 at the same depths. Below 15 cm depth (the depth of NUA incorporation) the PRI was similar in both amended and control sites.

- *Nitrogen*: TN, NH3-N and NOx-N fluxes to groundwater were reduced by 82%, 83% and 40%, respectively by NUA incorporated into the top 15 cm of soil on a 5% basis (w/w) at the start of the field trial.

pH: The amended plots (unfertilised and fertilised sites) had a pH of between 7 and 8. In contrast, both the control unfertilised and control fertilised sites were typically between 2-4 pH units lower with the control fertilised site having a final pH of 4.

Minor Elements: Two minor elements, cobalt (Co) and copper (Cu) were found to be enriched in the leachate from the amended fertilised or amended unfertilised plots.

Mechanism of Nutrient Removal by NUA

Geochemical analyses, modelling and petrography undertaken as a part of the field turf study have identified principal mechanisms for P uptake and retention by NUA-amended soil, and N removal.

P Removal: The result of gypsum dissolution is the saturation or near saturation of a number of Ca-bearing minerals in the NUA-amended soils, in particular calcite, dolomite, fluorite and hydroxyapatite,. Calcite and dolomite are known to bind P by surface adsorption or co-precipitation. In addition, formation of hydroxyapatite ($Ca_5(PO_4)_3OH$) is also one of the major mechanisms of P removal and retention within the NUA-amended soils.

A second key mechanism in the retention of P within the NUA-amended soils is a surface adsorption and/or co-precipitation of P onto the abundant Fe hydr(oxide)s which constitute a major mineralogical constituent of the NUA. Consistent patterns of oversaturation are apparent for both goethite and ferrihydrite in NUA amended soils.

N Removal: Two main mechanisms are assumed to be involved in nitrogen removal in NUA systems:

- Reduction in DON in NUA column effluent is likely the result of dissolved organic matter (DOC) retention of, and hence retention of DON, within the solid matrix. The NUA demonstrated substantial sorption capacity for DOC.

- Transformations of N species leading to nitrification-denitrification and net system N loss.

5.3.3 NUA in Brief

From the review of the CSIRO reports, the key NUA performance characteristics can be summarised as follows:

1. NUA showed excellent P removal efficiency over the length of all trials (~3 years).

2. NUA showed relatively good removal of organic N (DON and NH3-N), however this did show progressive decline with time.

3. In terms of inorganic N, results were inconclusive.

4. Physical properties of the materials (pH, porosity, EC) were stable for the duration of the experiments and appropriate for environmental applications.

5.4 POSSIBLE ISSUES & UNCERTAINTIES

Data from both column trials and the farm turf trials demonstrated the potential of using NUA as an environmental amendment for the attenuation and removal of DOC and nutrients (phosphorus and inorganic nitrogen) in large-scale nutrient intervention structures, such as the Ellen Brook project (End of Catchment Wetland Treatment System for Ellen Brook). However, there are several uncertainties and/or issues associated with the use of NUA which will need to be resolved in design of a full-scale system. This section is approached considering NUA as the major component of the treatment system.

The potential issues are outlined below.

5.4.1 Manganese Release

One of the main concerns related to the use of NUA as an adsorptive substrate in a large-scale treatment filter or constructed wetland is a significant release of manganese in the effluent water. Such an increase was observed from both of the column trials (Wendling *et al* 2009a and Wendling *et al* 2010) undertaken by CSIRO in which Ellen Brook water was used as a feed.

Column Trial 1 (Wendling *et al* 2009a):

- Mn concentration in Bassendean Sand reference column: max 0.35 mg/L Concentration of Mn in Bassendean Sand declined substantially after day 60 to close to detectible limits after day 80.

- Mn concentration in NUA column: equal or below 0.4 mg/L for the first 100-120 days, but then increases to 1.3 mg/L (~70% higher compared to Bassendean Sand reference column).

The pattern of Mn release in this study followed patterns of SO_4 and Ca reduction. In contrast to Ca and SO4 concentrations, Mn concentrations initially increased after approximately day 60 and then more substantially after day 90, attaining a maximum concentration of 1.3 mg/L in the NUA column effluent.

Column Trial 2 (Wendling *et al* 2010):

- Mn concentration in Ellen Brook: generally < 0.1 mg/L.

- Mn concentration in Bassendean Sand reference column: generally < 0.1 mg/L.

- Mn concentration in NUA column: up to 4 mg/L (97% increase compared to Ellen Brook water and Bassendean Sand reference column).

Guidelines & Environmental Toxicity

Australian and New Zealand Guidelines (ANZECC 2000) for Fresh and Marine Water Quality states the following trigger values for levels of manganese in fresh waters:

- 99% protection – 1.2 mg/L

- 95% protection – 1.7 mg/L

Therefore, levels of Mn detected in effluent from NUA columns exceeded the 99% level of protection in both Trials, and 95% protection in Trial 2.

In terms of manganese environmental toxicity, there is a wide range of toxicity values for algae and protozoa, some of which are below the observed levels in column trials. For example, for the freshwater Daphnid (*Daphnia magna*), tests revealed 48-h LC50/EC50 values starting from 0.8 mg/litre. Freshwater molluscs and crustaceans are thought to be the most manganese-sensitive freshwater invertebrates, followed by arthropods and oligochaetes (International Programme on Chemical Safety, 2004).

Manganese in water can be significantly bioconcentrated by aquatic biota at lower trophic levels. Bioconcentration factors (BCFs) measure the cumulative effect of a toxin as it 'multiplies' in the food chain. BCF's for Mn have been recorded at 2,000–20,000 for marine and freshwater plants, 2500–6300 for phytoplankton, 300–5500 for marine macroalgae, 800–830 for intertidal mussels, and 35–930 for fish have been estimated (International Programme on Chemical Safety, 2004). Therefore, toxicity needs to be considered not just in terms of the initial concentration in water, but the final and higher concentrations within the tissues of living organisms.

Release Mechanism

Mn oxides/oxyhydroxides are present in hydrated NUA and geochemical modelling showed that all three manganese minerals present in NUA (manganite, rhodochrosite and pyrolusite) were undersaturated to varying degrees during the NUA column trial (Wendling et al 2010). Manganese enrichment in the NUA column effluent is believed to be the result of microbially-mediated reductive dissolution of amorphous Mn oxide/(oxy)hydroxide minerals as anoxic conditions first established and then became increasingly prevalent within the NUA column (Wendling *et al.* 2009b).

In the first column trial, the greatest increase in dissolved Mn (post day 100) occurred simultaneously with associated increases in Fe and Al. It has been speculated that this release of Fe and Al could be due to dissolution of Fe-oxyhydroxides under anoxic conditions and associated substitution and release of Al (Wendling et al 2010). Mn release reached its zenith at day 160 after which Mn concentration declined, and this decline in Mn levels was paralleled with a reduction in Fe and Al concentrations. This transient behaviour of Mn release suggests that increasingly large areas of the NUA column were subject to sustained anoxia, probably due to microbial processes. The decline in Mn peak (post day 160) may have marked the exhaustion of reducible/labile Mn within these anoxic zones.

Release of Mn from NUA material could potentially be of concern and cause a range of unacceptable environmental impacts. The severity of these impacts however would vary greatly depending on:

- The proportion of NUA used within the system.
- If blended with other amendments, the type and proportion of the other media – while effluents from the NUA column exhibited increasing concentrations of Mn with time, most likely due to gradual mobilisation of Mn contained within the solid phase, NUA blends, NUA/SS (blend with Steelmaking by-product) and NUA/MgO (blend with calcined magnesia) did not display the same Mn release pattern as NUA singly, i.e. effluent from

columns filled with these two NUA blends contained low concentrations of Mn (Wendling et al, 2010).

- The location of NUA within the treatment system – for example, the presence of NUA within the Ellen Brook aquatic environment would pose an environmental risk during oxygen-depleted conditions, which is a characteristic, if only seasonally, of riparian wetlands; this would result in localised Mn release.
- The extent to which the flow rate to mass of media can be controlled to reduce the outlet of concentration of Mn at full-scale.

5.4.2 Sulfate Release

Another potential concern regarding the use of NUA in the Ellen Brook project is the release of sulfate from the material into the effluent waters. Again, this trend was observed in both column trials with Ellen Brook waters (Wendling et al 2009a and Wendling et al 2010).

Colum Trial 1 (Wendling *et al* 2009a):

- SO_4 conc in Bassendean Sand reference column: 25 – 75 mg/L
- SO_4 conc in NUA column: between 900 – 2,500 mg/L for the first 100 days of experiment (100 x increase compared to Bassendean Sand reference column); after 100 days sulfate levels in NUA column were reduced below 50 mg/L ; these observed changes in SO_4 concentrations in effluent waters followed the same pattern as Ca concentrations.

Colum Trial 2 (Wendling *et al* 2010):

- SO_4 conc in Ellen Brook water: 15 - 20 mg/L.
- SO_4 conc in Bassendean Sand reference column: 10-15 mg/L.
- SO_4 conc in NUA column: 1,300 – 1,800 mg/L (~ 100 x compared to Ellen Brook water and Bassendean Sand reference column).

Guidelines & Environmental Toxicity

Sulfate is one of the least toxic anions, and due to relatively low environmental impacts the release of sulfate has received little attention in many regulatory jurisdictions when compared to control of dissolved metals or acidity.

However, in natural environments high levels of sulfate in discharge waters entering natural water bodies can decrease water quality through the increase of acidity, metals and dissolved salts. In addition, reduction of sulfate which can occur in environments with reduced levels of oxygen (anoxic environments) and organic material, leads to the production of hydrogen sulfide (and other sulfides), which are potentially toxic to aquatic organisms.

Hence, while sulfate alone has relatively low environmental impacts, regulation of sulfate levels is important in controlling levels of sulfides, dissolved metals, total salts and acidity which are environmental contaminants of concern.

Increasing concern regarding the potential impacts of sulfate has led to the introduction of recommended guideline values, rather than standards, for sulfate in effluent discharge. These typically are based on USEPA or WHO guidelines as to the maximum concentration of a particular chemical constituent in drinking water or water utilized by livestock or for irrigation. These guidelines generally recommend no more than 500 mg/L sulfate (Bowell 2004). This trigger value is in line with the Australian Drinking Water Guidelines (2004), which sets a limit of 500 mg/L.

There are no set sulfate trigger values for the protection of fresh and/or marine waters (ANZECC 2000). It has been generally accepted that un-ionised H2S is primarily responsible for sulfide toxicity to aquatic ecosystems and H2S concentration and hence toxicity is dependent upon water pH, temperature and ionic strength (ANZCC 2000). Consequently, trigger value set for the concentration of un-ionised hydrogen sulfide (H2S) only, as follows:

- 99% protection – 0.5 µg/L
- 95% protection – 1 µg/L

Note, none of the trials reported on sulfide concentrations in effluent water

Release Mechanism

High concentrations of SO_4 (and Ca) within the NUA column effluent are the result of the dissolution of gypsum during the column trial.

In column Trial 1 concentrations of Ca and SO_4 in effluent were above 600 mg/L and 1,500 mg/L, respectively until day 90. This constituted a molar ratio of 1:1 in accordance with bassanite stoichiometry. As the effluent concentrations of both Ca and SO_4 declined the effluent became increasingly undersaturated with respect to both gypsum and anhydrite signalling the exhaustion of this primary phase (Wendling et al 2009a).

When concentrations of Ca and SO_4 began to decline the Ca:SO4 molar ratio began to progressively increase to a maximum of 3 by the end of the column trial. This net deficit of SO^4

relative to Ca is believed to be the result of SO_4-reduction. If this is the case, decline in sulfate will result in sulfide production which might have significant environmental impacts. However, the exact concentration of sulfides in trials with Ellen Brook water is not known at present.

Another possibility is the formation of schwertmannite which became increasingly oversaturated and thus may have been a substantial reservoir for excess SO_4 (Wendling et al 2009a). However, this hypothesis needs to be confirmed by CSIRO.

There are potentially two issues pertaining to sulfate release. Firstly, unless the release of water can be controlled (e.g. by running the system at a certain flow threshold), the increase in EC could be substantial and detrimental to a freshwater system, particularly over summer where evaporation effects will further increase the total salinity of the water and may result in microbial and plant decline or deaths. Secondly, high levels of sulfate may lead to sulfide generation where oxygen levels are low, which in turn can cause toxicity to plant roots and aquatic organisms.

While downstream effects will be negligible due to the significant dilution effects, the localised impacts due to sulfate release may result in a range of unacceptable environmental impacts (dependent on the proportion of NUA used within the system and influent flow rates).

5.4.3 Other Potential Issues

Breakthrough of DOC and NH_3-N

One of the main issues associated with the use of adsorptive substrates such as NUA is their ‘sorption capacity’ i.e. ability to effectively remove selective pollutants as a result of their particular physical properties in time. The question with all of these materials is when they will be spent leading to the cessation of contaminant removal, and if such materials are used for treatment of polluted water; this would lead to the reappearance of high contaminant levels (equal to influent levels) in effluent treated water (‘contaminant breakthrough’).

Such ‘breakthrough’ has been observed for some contaminants in Column Trial 1 in which NUA columns were used to treat influent Ellen Brook water.

<u>Column Trial 1</u> (Wendling *et al* 2009a):

- Breakthrough of DOC in column effluent was observed following approximately 150 days of column operation.
- Clear breakthrough was observed for NH_3-N following 78 days column operation.

- In terms of DON, clear breakthrough was not observed for the duration of the trial (180 days), however based on the data presented in the trial report (Figure 7, Wendling et al 2009a) it could be speculated that such breakthrough could be expected if monitoring was extended past 180 days.

<u>Column Trial 2</u> (Wendling *et al* 2010):

Clear breakthrough was not observed for monitored contaminants during the Trial 2, although this trial was run for a longer period of time compared to the Trial 1 (370 vs 180 days). However, the amount of NUA present in Trial 2 columns was markedly greater compared to columns in Trial 1; in Trial 1 NUA was ~ 23% (v/v) while in trial 2 it was 40% (v/v).

If NUA is to be incorporated into the Ellen Brook treatment system, the sorption capacity of this material for different contaminants which have been estimated in column trials (see Wendling *et al* 2009a, Table 2) need be established and confirmed in full-scale systems. These sorption capacities must be included in the system design to ensure required treatment efficiency and in order to develop an appropriate management plan (e.g. adequate volume of NUA in system and timely replacement of NUA materials to avoid contaminant breakthrough).

Other contaminants

<u>Calcium (Ca) and Magnesium (Mg) and TDS</u>

Effluents from NUA columns were characterised by high concentrations of magnesium and in particular calcium.

Calcium

Column Trial 1: Ca concentrations in NUA columns varied between 400-1000 mg/L for the first 100 days, than was reduced to below 50 mg/L. This concentration pattern followed sulfate concentration pattern as explained above.

Column Trial 2: The cations Ca, Mg, K, S and Na were only monitored for approximately the first three months of the column trial.

- Ca concentration in Ellen Brook water was <50 mg/L.
- The concentrations of both Ca (~600 mg/L) and S (~600-650 mg/L) were high in effluents from NUA columns throughout the measurement period.

Molar ratios of Ca and S in effluents from NUA columns were in accordance with gypsum stoichiometry of 1:1, indicating that Ca enrichment of NUA effluents can be attributed to dissolution of gypsum contained within the NUA.

In addition to contributing to the salinity of water, high levels of calcium can also impact on normal biological / biochemical functioning of plants (including wetland plants) via many critical roles this cation plays in plant physiology. For example, calcium fluxes have been implicated in plant responses to various environmental stresses, such as salinity and acidification, because of its early role in signalling membrane imbalance. Calcium is necessary for the effective competition of potassium with sodium for potassium uptake via both the 'low-affinity' or passive system and the 'high affinity' or active pathways (Zhu, 2003). However, calcium excess impedes the uptake of magnesium and potassium ions. It also decreases the availability of nitrogen, phosphorus, iron, and zinc.

Magnesium

Column Trial 2: Mg concentration of Ellen Brook water was < 10 mg/L, while in NUA columns Mg conc was ~40-70 mg/L. Mg concentration exhibited a peak after the passage of approximately 20 days of column operation.

The NUA solid phase has also been shown to contain 1.8% Mg (w/w) (Wendling *et al.*, 2009b), most likely as an impurity in gypsum/anhydrite where Mg may substitute for Ca in the mineral structure. Hence, dissolution of gypsum also results in the release of Mg.

Mg competes with other major cations such as calcium (Ca^{2+}), potassium (K^{+}), sodium (Na^{+}), ammonium (NH_4^{+}), iron (Fe^{2+}), and aluminium (Al^{3+}) for plant uptake. Similarly to Ca, high levels of Mg can reduce K uptake resulting in potential potassium deficiency in plants.

An increase in Ca and Mg levels contribute to increased salinity, which can be an issue for the overall performance of the biological wetland system proposed for the Ellen Book project. This may be an issue during the summer period when flows are minimal and evaporation is very high leading to localised increases in the salinity. TDS was not reported on in the trials, but given the range and concentrations of individual salts (sulfate, Ca, Mg), an undiluted stream passing through the NUA media may at times contain a TDS of ~3000ppm, before evapo-concentration within the wetland (i.e. above the threshold of many organisms). Elevated Ca also limits nutrient removal via plants. Managing influent flow rates to manage leachate concentrations will be necessary.

Cobalt (Co) and Copper (Cu)

As previously outlined, the study at the Bullsbrook Turf Farm showed that the microelements cobalt (Co) and copper (Cu) were enriched in leachate from NUA amended sites (control un-fertilised and fertilised).

Cobalt

- Co in leachate from controlled fertilised & un-fertilised soil – 0.8 µg/L and 0.38 µg/L
- Co in leachate from amended fertilised & un-fertilised soil – 2 µg/L and 0.53 µg/L

Increase of 1.2 µg/L (fertilised) and 0.15 ug/L (un-fertlised sites) due to the NUA amendment.

ANZECC guidelines for cobalt: Low reliability freshwater trigger value of 1.4 µg/L.

Copper

- Cu in leachate from controlled fertilised & un-fertilised soil – 791 µg/L and 380 µg/L
- Cu in leachate from amended fertilised & un-fertilised soil – 1975 µg/L and 534 µg/L

Increase of 1184 µg/L (fertilised) and 154 µg/L (un-fertlised sites) due to the NUA amendment.

ANZECC guidelines for copper: A freshwater high reliability trigger value for Cu is 1.4 µg/L for the 95% level of protection.

Cu and Co were not monitored in column trials 1 and 2, so their exact concentrations in effluent and their possible environmental impacts, are not known at present. If NUA is to be used in large scale field applications such as Ellen Brook project, the potential Co and Cu-related environmental impacts of NUA, if any, needs to be clarified.

Ecotoxicology

Ecotoxicological testing of NUA was undertaken by CSIRO as part of detailed analysis and characterisation of NUA material (and other mineral-based by-products) (Wendling *et al* 2009b).

Leachates of NUA were prepared and subjected to toxicity testing to evaluate potential impacts on water quality. Test data showed that NUA leachate was not toxic to *Vibrio fischeri* (bacteria) and *Ceriodaphnia dubia (freshwater crustacean)*, and it showed minor toxicity in algal growth rate tests (*Chlorella* sp. 12 algae).

The main uncertainties related to these toxicological results are as follows:

- At higher concentrations (33% and higher) NUA leachate significantly inhibited algal growth in 72-hour algal growth rate toxicity tests.

- Testing was done only on three selected species. Given NUA may be used in combination with wetlands in the full scale treatment system which will be positioned within, and discharging into the complex aquatic system of Ellen Brook waters, impacts on other aquatic species (e.g. fish, amphibian, annelids), and impacts on native plants also need to be tested.

- Before NUA is included in the full-scale long-term treatment system, chronic effects of NUA on a broader range of target species specific to the Swan River also need to be studied.

- Similarly, in all undertaken ecotoxicity tests leachate was obtained after 18 hrs of NUA mixing (mixed by tumbling end-over-end at 30±2 rpm). Analysis of this leachate revealed the presence of several trace elements at levels that were higher compared to the softwater control (method blank) (≥2 times) including Ba, Ca, Cl, Cr, F, K, Mg, N, (primarily as NO_x-N), Na, Rb, S, Si, Sr and U. However, in a full scale system there will be continuous prolonged leaching of NUA materials into the aquatic phase as a result of changes in NUA mineral structure over time. This may result in higher concentrations of some of those detected trace elements or even appearance of other elements that were not detected in ecotoxicological studies, such as manganese which has been found in elevated concentrations in NUA column effluents (see Section 5.4.1 above).

- Possible impacts of different conditions within the full-scale NUA system, e.g. anoxic vs aerobic conditions, wet vs dry sediment should be assessed once a preliminary design has been resolved.

As commented by the authors of the CSIRO studies (Wendling et al 2009, p4), "it is clear that to assess the potential ecotoxicological risk associated with the use of any material as an environmental amendment, long-term investigation is required under varying environmental conditions in order to accurately predict the fate and behaviour of potentially toxic elements within the system". It would be prudent to do more tests using different species from several different trophic levels, and include specific Swan-Canning species (e.g. the freshwater copepod, *Macrocyclops albidus*, and the pygmy perch, *Edelia vittata*).

Flows

In both column trials flows through the NUA column were constant and relatively low, meaning the media was constantly saturated during the course of the column trials. Thus, it is not known how NUA system would behave in terms of its performance and mineralogical stability under wet-dry and variable hydraulic loading conditions. Given Ellen Brook is a river system where flows are higher than those currently tested in experiments, and is highly variable in flow rates and periodicity seasonally and annually, this will present major challenges.

The issue of flow rates also significantly affects the sizing of the system and the volume of water to 'leachate' released from the NUA media (i.e. the dilution effect).

Therefore, there is a level of uncertainty regarding the performance of NUA in full-scale system with high and variable flows. Constant flows can be provided by continuous pumping of water through the NUA system component. However, this brings certain design constraints such as the need for large, energy consuming pumps that would need to operate year around, and constant recirculation of water which can lead to increase in salinity especially in summer periods, etc.

5.5 SUMMARY OF NUA

The key uncertainties associated with the use on NUA as an environmental amendment medium in full-scale system such as the one proposed for Ellen Brook, can be summarised as follows:

1. *Contaminants breakthrough* – reappearance of high levels of some contaminants such as DOC, NH3-N or even DON in the effluent treated water as a result of reactive phase being spent in the system.
2. *Flows* - uncertainty regarding the performance of NUA in full-scale system with high and variable flows.
3. *Environmental impacts* – due to the potential release of Mn at levels that may cause impacts on the receiving aquatic environment - this will depend on the ratio of NUA to other amendments and flow rates.
4. *Increase in salinity* – due to release of high levels of Ca, Mg and in particular SO_4 from hydrated NUA. High salinity can have negative impacts on a freshwater system, and can impede the overall water quality of the Ellen Brook river system, as well as the habitat wetland proposed for end-of-catchment. This may be a significant issue during the summer period when flows are minimal and evaporation is high.
5. *Sulfide generation* – release of high SO_4 levels from NUA can, under anaerobic/anoxic conditions, result in sulfate reduction and generation of sulfide which in turn can cause toxicity to plant roots and aquatic organisms.
6. *Additional toxicity of NUA leachate* – it is possible that over the long life-time of the full scale system continuously exposed to high and potentially variable flows, NUA leachate may have some additional toxicological effects on the aquatic environment.

It is noted that many of these uncertainties and potential issues can be managed by the proportion of NUA used in the system and what additional amendments form the preferred blend, where the NUA is used in the system, what flow rates it can sustain (i.e. its actual hydraulic permeability), and how often it is replaced. In other words:

- If smaller volumes of NUA are used in the treatment system, this will lead to smaller release of Mn, Ca, Mg and sulfate reducing many of the risks and negative impacts associated with NUA use (outlined above). However, use of smaller NUA volumes would increase the risk of contaminant breakthrough jeopardising the total system performance and imposing the need for frequent media replacement.

- On the other hand, use of greater NUA volumes would remove or significantly postpone contaminant breakthrough ensuring high level of system performance over an extended period of time and reducing the maintenance and replacement needs. However, increase in NUA would most likely result in greater release of Mn, Ca, Mg, sulfate and possible other contaminants.

- If the blend of NUA has a high hydraulic permeability, the likely volume of water to mass of contaminants in the NUA may provide sufficient dilution to manage most of the potential contaminant issues.

However, in order to design and manage NUA as a treatment option for Ellen Brook, these key challenges must be addressed and is dealt with in subsequent report sections (see Sections 8.0 and 9.0).

5.6 ADDITIONAL INFORMATION & PILOT STUDY

The NUA pilot study, an initiative between the Trust and CSIRO, is currently underway and will provide additional information and data critical to determine the issues and uncertainties with the in-situ application of NUA. As the results of this trial were not available at the time of this report, the scope of this feasibility study reflects data from the column and turf trials only.

Further review of these ‘combination amendments’ will be required after the completion of the CSIRO pilot study.

Since the provision of reviewed reports (see Section 5.1.2), additional information and data has become available and will continue to become available as the CSIRO/SRT pilot study progresses. All new information regarding the characteristics and ‘fate’ of NUA and in particular its performance in pilot studies will have to be progressively addressed in later phases of this Ellen Brook project. For example, in light of additional information received from CSIRO it is acknowledged that a blend of NUA with calcinite may be the preferred solution for the full scale system. Further review of these combination amendments is warranted to address benefits and limitations of these mixes, and particular design requirements needed to efficiently deal with any particular constraint of any given mix.

In other words, a detailed review of the amendment combinations and dilution factors will be required in addition to this feasibility study. This additional review should reflect the outcomes of the pilot trial and will be useful to determine whether the key issues identified below are still relevant and will allow the identification of any additional issues.

6.0 DATA GAPS

A number of data gaps exist within the current literature review. The confirmation of the most appropriate material is difficult to ascertain with the current reports and data provided. Data gaps that will need to be addressed prior to commencement of Stage 2 phase of works include:

- Daily flow data for Ellen Brook (from gauging station 616189);
- All available water quality data for Ellen Brook (from gauging station 616189);
- Groundwater data, including aquifer and perched groundwater tables, water quality and interaction with Ellen Brook;
- Saturated hydraulic conductivity of NUA and sand media (non-pressurised);
- NUA leachate and toxicological characteristics (further information/data required);
- Performance of NUA under wetting and drying cycles;
- Performance of NUA under differing flow velocities; and
- Residence/contact time required for NUA removal of TN and TP.

TASK 2: SITE OPPORTUNITIES & CONSTRAINTS

7.0 SITE LOCATION

The two sites selected by the Trust for the purpose of an end of catchment treatment system are located in the suburb of Belhus and are immediately upstream of the confluence of Ellen Brook with the Swan River. These sites were originally identified in the GHD (2007) report as Site 23 and Site 24. Site 1 (formerly site 24) is located to the north of West Swan Road Bridge and extends upstream of Cruse Road to the north east and Millhouse Road to the north west. Site 2 (formerly site 23) is located to the east of Millhouse Road bridge and extends upstream to Ellen Brook Drive. Figure 5 shows the location of Site 1 and Site 2.

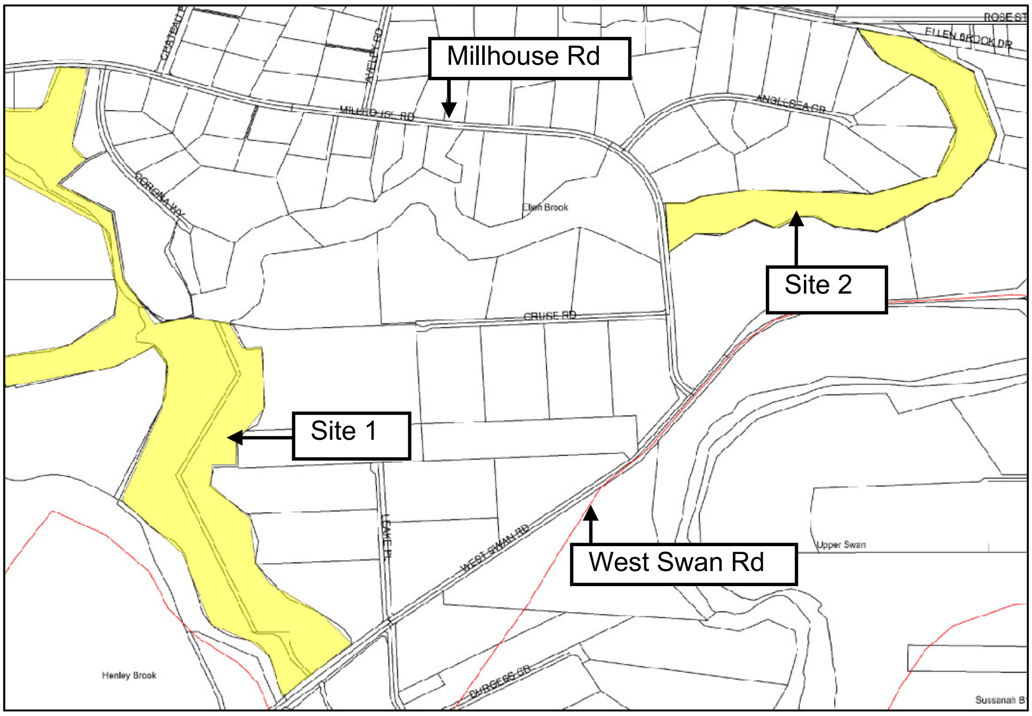


Figure 5 Location of Site 1 and Site 2 (from Department of Environment 2010; Trust 2010)

8.0 OPPORTUNTIES AND CONSTRAINTS IDENTIFICATION

Table 12 identifies opportunities and constraints for Site 1 and Site 2 in an environmental, social, regulatory and economic context. Table 13 identifies opportunities and constraints for use of NUA as an end of catchment treatment. Outcomes of these opportunities and constraints are presented in the design implications section of this report (section 9.0).

Table 12 Site 1 and Site 2 opportunities and constraints (1 of 3)

		OPPORTUNITIES		CONSTRAINTS	
		SITE 1	SITE 2	SITE 1	SITE 2
ENVIRONMENTAL CONTEXT					
CLIMATE	**Rainfall** (660 mm/yr to 820 mm/yr)	▪ Stormwater harvesting and reuse		▪ Large flow volumes and high flow velocities are difficult to treat via traditional stormwater treatment measures (wetlands, bioretention, buffers etc)	
CLIMATE	**Evapotranspiration** (1934 mm/yr)	▪ Vegetation interception, uptake and transpiration of surface water and groundwater		▪ Stakeholder resistance to revegetation and buffers	
SOILS & LANDFORM	**Topography** (Site 1: Gentle channel with steep elevated embankments, Site 2: Gentle channel and embankments)	▪ Confinement of flows to channel allows greater control of volumes, velocity and storage ▪ Long channel allows for multiple treatment train elements, greater residence time and increased hydraulic effectiveness ▪ Gravity fed treatment system ▪ Interventions can be integrated with the embankments (e.g. weirs)	▪ Good site access (construction and maintenance) due to gently sloping embankments ▪ Wide channel allows for multiple treatment elements	▪ Poor site access (construction and maintenance) due to steep embankments ▪ Channel constricts available area within Site 1 to 11 ha ▪ Potential embankment erosion may restrict the use of some interventions	▪ Flat topography makes it difficult confine and treat flows (potential flooding at site and upstream) ▪ Boggier ground
SOILS & LANDFORM	**Soil** (Typically Bassendean sands characterised by low PRI and potential ASSM risk)	▪ High porosity soils could be utilised for infiltration (i.e. disposal to land)		▪ Excavation and disturbance to Bassendean sands needs to be minimised due to potential release of large volumes of stored sediments and nutrients ▪ Low PRI in soils constricts the potential for land based stormwater disposal ▪ Potential ASS risk	
BIODIVERSITY	**Vegetation** (Grassed sump land & areas of trees & shrubs)	▪ Little native vegetation clearing is required ▪ Revegetation of sump land will increase existing habitat, biodiversity and visual value		▪ Stakeholder resistance to revegetation (shrubs & trees) due to fire risk & visual amenity	
BIODIVERSITY	**Fauna** *(Aquatic/terrestrial fauna*	▪ Enhancement of aquatic and terrestrial fauna habitat via revegetation		▪ Protection of existing aquatic and terrestrial fauna and habitat (including maintaining fauna/fish migration)	

Site 1 and Site 2 opportunities and constraints (2 of 3)

		OPPORTUNITIES SITE 1	OPPORTUNITIES SITE 2	CONSTRAINTS SITE 1	CONSTRAINTS SITE 2
ENVIRONMENTAL CONTEXT					
SURFACE WATER	**Runoff** (From surrounding land)	▪ Interception of runoff prior to entry to Ellen Brook			
SURFACE WATER	**Ellen Brook** (Flow volumes through Ellen Brook of approx. 30 GL/annum)	▪ End of line approach allows for cost effective treatment of large flow volumes and nutrient loads prior to entry to the Swan River		▪ Large flow volumes and high flow velocities are difficult to treat via traditional stormwater treatment measures (wetlands, bioretention, buffers etc) ▪ End of line approach could increase flooding risk (site and upstream) ▪ Variability of flows and nutrient loads ▪ Uncertainty of flow volumes, and nutrient loads associated with particular flows	
GROUNDWATER	**Perched Groundwater** (discussion)	▪ Interception of perched groundwater prior to Ellen Brook		▪ Mobilisation of nutrients via groundwater ▪ Groundwater interaction with intervention ▪ Uncertainty of perched groundwater and groundwater contribution to instream flows	
GROUNDWATER	**Aquifer**	▪ Controlled aquifer recharge as reuse		▪ Uncertainty of aquifer contribution to instream flows	
INFRA	**Infrastructure**	▪ Good connection with existing roads and services Gauging stations integrated with bridges		▪ Protection of bridge crossings from flooding and high velocity flows ▪ Limited power infrastructure at site	
SOCIAL CONTEXT					
SUSTAINABILITY ATTITUDES	**Community**	▪ Community involvement with implementation of intervention		▪ Reluctance to revegetate with some plant species due to fire risk	
SUSTAINABILITY ATTITUDES	**Government Stakeholders**	▪ Government support for reducing nutrient load entering Swan River from Ellen Brook			
SUSTAINABILITY ATTITUDES	**Developers**	▪ Integration of proposed residential development with the intervention		▪ Access from private road within new development	

Site 1 and Site 2 opportunities and constraints (3 of 3)

<table>
<tr><th></th><th></th><th colspan="2">OPPORTUNITIES</th><th colspan="2">CONSTRAINTS</th></tr>
<tr><th></th><th></th><th>SITE 1</th><th>SITE 2</th><th>SITE 1</th><th>SITE 2</th></tr>
<tr><td colspan="6">REGULATORY CONTEXT</td></tr>
<tr><td rowspan="3">TENURE, ZONING & LANDUSE</td><td>Tenure
(Sites are government owned, surrounding land is privately owned)</td><td colspan="2">▪ Government owned land (existing wetland and sump land)</td><td colspan="2">▪ Privately owned land in close proximity (fence line within floodplain)
▪ Increase in residential development will increase flow volumes and nutrient input</td></tr>
<tr><td>Zoning
(Mainly rural, zoning with increasing residential zoning to the west of Ellen Brook)</td><td>▪ Ellen Brook and sump land zoned as Swan Valley rural</td><td>▪ Ellen Brook and sumpland is zoned as parks and recreation</td><td>▪ Conservation and multiple use classifications apply to Site 1.
▪ Will require further liaison with DEC</td><td></td></tr>
<tr><td>Landuse
(Mainly agricultural, residential to the west)</td><td colspan="2">▪ Existing and proposed residences could integrate BMPs (WSUD, buffers etc)
▪ Surrounding Swan Valley rural zoning could utilise BMPs (soil amendments, fertiliser efficiency, buffers, reuse etc)</td><td>▪ Retainment of existing amenity within residential areas, including views from residences</td><td>▪ Large private property pond close to existing wetland (flood risk)
▪ Retainment of existing amenity within residential areas, including views from residences</td></tr>
<tr><td rowspan="2">HERITAGE</td><td>Aboriginal
(Aboriginal sites of significance located in close proximity)</td><td colspan="2">▪ Reintroduction of wetlands to the area that were historically part of the landscape</td><td colspan="2">▪ Potential Aboriginal sites of significance (requires further liaison)</td></tr>
<tr><td>European
(Heritage Mill to the north of Site 1)</td><td>▪ Integration of the Mill with the design</td><td></td><td>▪ Limits the extent of the intervention and may effect design water level (potential flood risk)</td><td></td></tr>
<tr><td colspan="6">ECONOMIC CONTEXT</td></tr>
<tr><td rowspan="2">FUNDING</td><td>Government</td><td colspan="2">▪ Some government funding is already allocated to project</td><td colspan="2">▪ Limited funding will require economically efficient interventions</td></tr>
<tr><td>Private</td><td colspan="2">▪ In kind contribution from suppliers of NUA
▪ Funding from developers adjacent to the site</td><td colspan="2"></td></tr>
</table>

Table 13 NUA opportunities and constraints (1 of 3)

NUA	OPPORTUNITIES	CONSTRAINTS / UNCERTAINTIES
Physical Characteristics		
Particle size between 500-1000 μm; most particles <63 μm in mean diameter Porosity is 0.59; saturated hydraulic conductivity is 0.54 cm/min. pH - generally in circumneutral range (6.0-8.0), EC - moderately high (2.54 mS/cm) Physical properties (pH, porosity, EC) were stable for the duration of the trial experiments.)	▪ Physical properties are appropriate for environmental applications, such as Ellen Brook system.	
Ecotoxicity		
NUA leachate enriched in Ba, Ca, Cl, Cr, F, K, Mg, N, Na, Rb, S, Si, Sr and U. Leachate was obtained after 18 hrs of NUA mixing. No significant toxicity in three tested species (Ceriodaphnia dubia , Vibrio fischeri and Chlorella sp.12).	▪ Opportunities for NUA to be used as an environmental amendment in water-based systems.	▪ Further toxicological studies required including longer terms studies of continuous prolonged leaching of NUA materials into the aquatic phase and chronic effects of NUA leachate on aquatic species. ▪ Impacts on other aquatic species (e.g. fish, amphibian, annelids), and impacts on native plants need also to be tested.
Radiological Analysis		
Radioactivity is greater than the UNSCEAR guideline		▪ NUA needs to be mixed with other materials to improve suitability for environmental application.
Perfomance Contaminant		
Phosphorus: Excellent P removal efficiency over the length of all trials (~3 years). Main mechanisms of P removal are adsorption or co-precipitation and formation of hydroxyapatite Nitrogen: Good removal of organic N (DON and NH3-N) and DOC. Main mechanisms of N removal are sorption to organic matter and transformation. Inconclusive results for inorganic N removal	▪ Opportunities for NUA to be used as an environmental amendment for the attenuation of waters containing high concentrations of labile P, DON and DOC - use as an adsorptive substrate in nutrient intervention structures such as in a large-scale treatment filter systems.	▪ Performance data available only from column trial experiments with Ellen Brook water (~ 18 months trials) and turf trials. There is a need for data validation in longer, pilot scale studies using Ellen Brook water or similar.

NUA opportunities and constraints (2 of 3)

OPPORTUNITIES	CONSTRAINTS / UNCERTAINTIES
Perfomance Contaminant (cont.)	
Contaminant breakthrough: Breakthrough of DOC and NH3-N, and potentially DON after few months of system operation (100-180 days) No P breakthrough observed during column experiments (~380 days)	▪ The sorption capacity of NUA for different contaminants need be established and confirmed in full-scale systems. ▪ Potential requirement for frequent replacement of NUA materials to avoid contaminant breakthrough ▪ Sorption capacities must be included in the system design to ensure required treatment efficiency and in order to develop an appropriate management plan.
Flows: In both column trials flows through the NUA column were constant and relatively low, meaning the media was constantly saturated during the course of the column trials.	▪ Uncertainty regarding the performance of NUA in full-scale system with high and variable flows. ▪ Need for large, energy consuming pumps that would need to operate year around, and constant recirculation of water which can lead to increase in salinity especially in summer periods.
Performance - Associated Pollutant Release	
Manganese - significant release of Mn in the effluent water passing through NUA material. Levels of Mn exceeded the 99% level of protection in both Column Trials and 95% protection in Trial 2. Mechanism of Mn release - microbially-mediated reductive dissolution of amorphous Mn oxide/(oxy)hydroxide minerals under anoxic conditions.	▪ Occurrence of oxygen-depleted conditions, within the treatment system if only seasonally, will result in Mn release. This is could cause a range of unacceptable impacts on the receiving environment.

NUA opportunities and constraints (3 of 3)

OPPORTUNITIES	CONSTRAINTS / UNCERTAINTIES
Performance - Associated Pollutant Release (cont.)	
Sulfate - significant release of sulfate in the effluent water passing through NUA material. In NUA column trial experiments, sulfate concentration in effluent was up to 2,500 mg/L, which was 100 times higher compared to Ellen Brook water. Mechanism of sulfate release - dissolution of gypsum.	▪ Sulfate release increases effluent EC. This EC increase could be substantial and detrimental to a freshwater system, particularly over summer where evaporation effects further increase the total salinity of the water. This may cause microbial and plant decline and/or deaths within the treatment system, reducing the overall system performance. ▪ High levels of sulfate may also lead to sulfide generation where oxygen levels are low, which can cause toxicity to plant roots and aquatic organisms.
Calcium, Magnesium, and TDS - Effluents from NUA columns were characterised by high concentrations of Mg (up to 70 mg/L) and in particular Ca (~600 mg/L).	▪ An increase in Ca and Mg levels contribute to increased salinity, which can be an issue for the overall performance of the biological wetland system. ▪ This is a particularly significant issue during the summer period when flows are minimal and evaporation is very high leading to further increase in the salinity.
Cobalt and Copper - Co and Cu were enriched in leachate from NUA amended sites in turf study. Concentrations of both metals were above ANZECC guideline trigger value.	▪ Risk of potential environmental impacts in full-scale system. ▪ If NUA is to be used in large scale field applications such as Ellen Brook project, the magnitude of potential Co and Cu- related environmental impact of NUA need to be clarified.

9.0 DESIGN IMPLICATIONS

9.1 DESIGN CRITERIA

Design criteria provides the framework for the design recommendations and options development. Design criteria reflect the opportunities and constraints identification (section 8.0), literature review (section 4.0 and 5.0) and aims of the project (section 2.0). Design criteria for the Ellen Brook project is presented below.

- *Water Quality:* Surface and groundwater quality shall be maintained to ambient conditions and/or enhanced to protect flora and fauna. Water quality shall be in accordance with *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC & ARMCANZ, 2000) and SCWQIP/HRAP nutrient concentration targets.

- *Water Quantity:* Surface water within Ellen Brook, or other tributaries within the catchment, shall not be permanently abstracted as stipulated by the DoW sustainable diversion limits (SDL).

- *Ecological Protection:* Environmental flows shall be maintained in accordance with the environmental flow objectives presented in the SCWQIP (refer SCWQIP section 8.3). Existing vegetation with conservational significance shall be identified and protected where possible.

- *Infrastructure Protection*: Existing infrastructure, including roads, bridges, electricity, sewer, water and telecommunications shall be identified, preserved and protected from flooding and construction works in accordance with service provider standards.

- *Cultural Protection:* Private properties and Aboriginal and European heritage sites, including the Mill site, shall be protected from flood events and construction and maintenance activities. Access to private properties and views from properties shall be maintained.

- *System Maintenance and Operation:* Maintenance requirements shall be minimised. Replacement of NUA and related components shall take place no more than once per annum. Access to treatment systems shall be clear and easy to navigate by both vehicles and personnel. Operating costs shall be in line with an agreed budget provided by the Trust and other relevant stakeholders.

- *Monitoring:* Configuration of the treatment system shall allow for regular water quality and quantity monitoring.

- *Life Cycle:* Where possible, all materials removed from the treatment system shall be reused by appropriate parties.

9.2 DESIGN APPROACH

Water Quality

- A maximum of 25% of total flows (6.7 GL) shall be treated through the NUA filtration system in order to maintain water quality levels, particularly for manganese and sulphate, in accordance with ANZECC & ARMCANZ guidelines.
- NUA shall be utilised to provide a majority of TN and TP reductions.
- Wetlands shall be utilised to provide limited TN and TP reductions. Wetlands shall be located at the terminal end of the NUA filtration system to polish flows prior to discharge.
- Disturbance to existing site soils shall be minimised. Sediment and erosion controls shall be implemented.
- The end of catchment treatment system shall form part of a suite of management actions (treatment train) implemented within the Ellen Brook catchment. Other management actions may include: riparian revegetation, perennial pastures, fertiliser efficiency, landuse change controls, fertiliser action plans and soil amendments.

Water Quantity

- Treatment systems shall not permanently abstract water from Ellen Brook. Systems such as aquifer recharge and/or land disposal shall not be utilised for nutrient reductions.
- Hydraulic capacity and conveyance of the existing site shall be maintained to pre-development conditions.

Ecological Protection

- Stream morphology shall be maintained to existing conditions to protect environmental flows and existing habitat.
- Riparian and wetland revegetation works shall be integrated with existing significant vegetation. Revegetation works shall be implemented throughout the site to intercept surface runoff and perched groundwater flows, control potential weed spread and enhance habitat and biodiversity opportunities.

Infrastructure Protection

- Access to the treatment system shall preferably be via West Swan Road (Site 1) and Millhouse Road (Site 2).
- Hydraulic capacity and velocity shall be maintained to existing conditions to ensure protection of West Swan Road, Millhouse Road and Cruse Road.

Cultural Protection and Enhancement

- Aboriginal heritage site identification and consultation shall take place prior to commencement of conceptual design works.
- Access to the treatment system via roads adjacent to private properties shall be limited where possible.
- Revegetation works shall maintain existing view corridors from private properties.
- Community engagement and involvement prior and post construction.

System Maintenance and Operation

- Configuration of the treatment system shall allow for easy access, maintenance and, when necessary, replacement.
- Gravity fed systems shall be optimised to reduce operation costs.

Monitoring

1. Monitoring sites shall be located upstream and downstream of the treatment system. Monitoring programs shall be developed consistent with current standards.

10.0 WATER QUANTITY AND QUALITY MODELLING

10.1 WATER QUANTITY

Water quantity modelling is based on daily streamflow data from the Ellen Brook Railway Parade gauging station (station reference 616189) for the years 1997 - 2006. This time series represents the 40th percentile average annual streamflow based on 1966-2009 data. As this monitoring station is located upstream of the confluence with the Swan River, it does not account for the total flow discharging from Ellen Brook to the river. To take into account additional flows downstream of the gauging station a scale factor of 1.26 was applied to equate the gauging station data with total streamflow estimates. The scale factor reflects the difference between the average annual data from the gauging station (21.2 GL/year) and the estimated total stream flow cited in a number of sources (Trust 2009a, Kelsey at al. 2010) for the same period (26.75 GL).

In line with the Water Quality Design Approach (section 9.2), it is recommended that a maximum of 25% of total average flows (6.7 GL) are treated through the NUA treatment system, whether it be an active or passive system, to ensure dilution of NUA effluent. Water quantity modelling investigated diversion of the 25th and 25th - 50th percentile of flows as shown in Figure 6 and Figure 7.

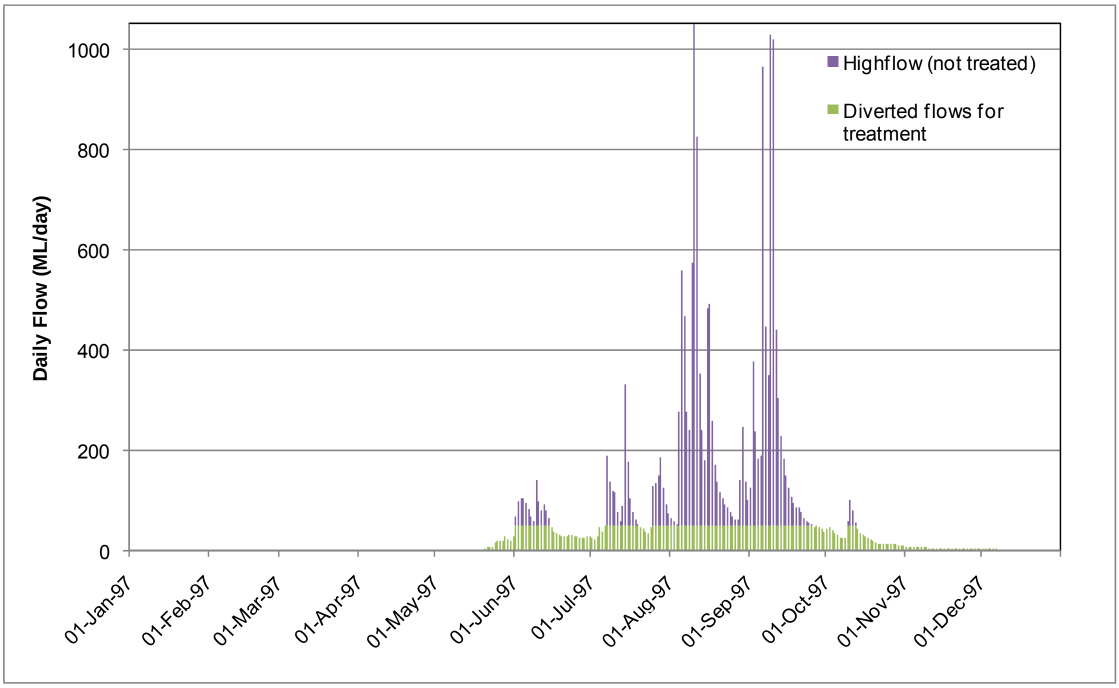


Figure 6 25th percentile flows diverted (shown for year 1997)

Figure 6 shows the 25th percentile flows diverted to the treatment system. All flows above the 25th percentile will bypass the treatment system, whereby a majority of flows from August to October will bypass the system and remain untreated. <u>This approach will require a maximum diversion of 50 ML/day and 50ML of storage, assuming that the water is turned over/treated over a 24 hour period</u>.

Diversion of the first 25th percentile of flows will require structures such as fish ladders and adequate low flows to maintain fauna passage.

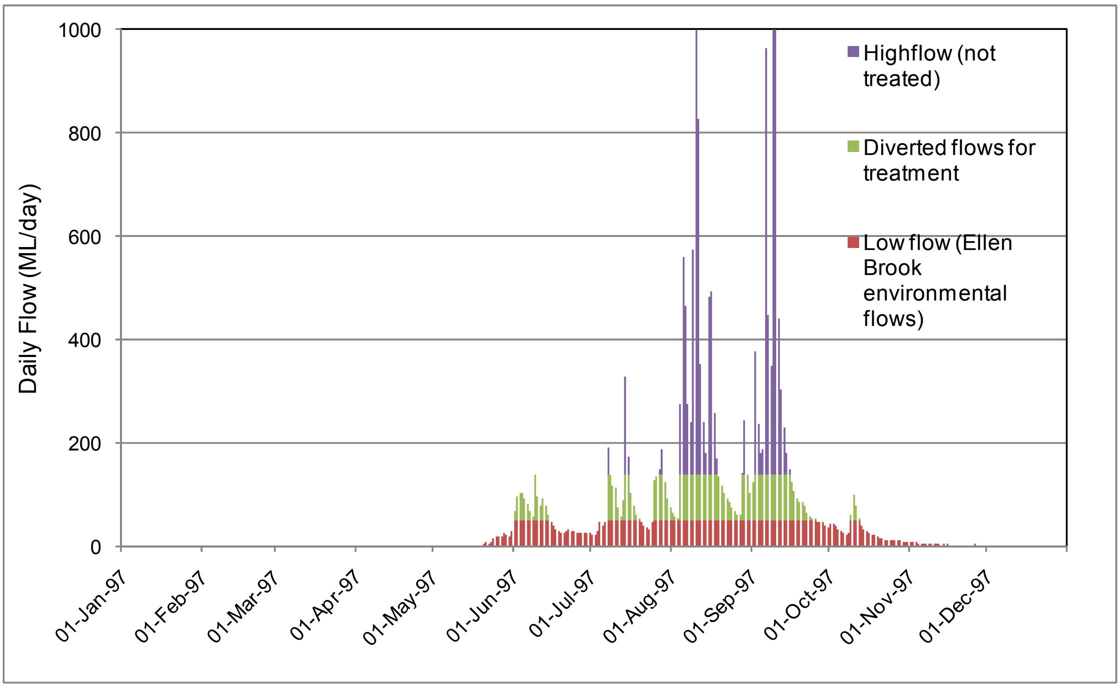


Figure 7 25th- 50th percentile flows diverted (shown for year 1997)

Figure 7 shows the diversion of up to the 50th percentile flows, allowing the 25th percentile flows to bypass both the storage and the treatment system. This approach requires a maximum diversion of 90ML/day and 90ML of storage assuming the water is turned over in a 24 hour period. This is due to the requirement to capture the event flows as opposed to capturing the low flows.

The illustration presented in section 11.2.5 identifies that 3.6 ha of area could be utilised for storage within Site 1. Assuming that this is the case, storage of the 25th percentile flows (50 ML) would require an average effective storage depth of 1.5 m. Comparatively, storage of the 25th - 50th percentile flows (90 ML) would require an average effective storage depth of 2.5 m. In order to limit the average effective storage depth to 1.5 m for the 90 ML diversion scenario, an area of 6 ha is required for storage, leaving little area available for the provision of wetlands and other environmental and social amenities. Discussions with the Project Working Group and the Trust indicated the preference for low weirs in combination with wetlands to provide a suite of social and environmental benefits. As a result, all conceptual options presented below are based on treatment of the 25th percentile flows.

10.2 WATER QUALITY

Water quality modelling was based on 25% of the total average stream flows being diverted to the NUA blend treatment system. Assuming maximum removal efficiencies of 60% for TN and 98% for TP can be achieved by the NUA, treatment of 25% of the total flow equates to a 15.4% load reduction in TN and 25.1% load reduction in TP. A nutrient balance presented in

Figure 8 highlights that the NUA treatment system provides a majority of nutrient reductions, with the wetland providing minimal nutrient reductions. Whilst the wetlands offer little nutrient reductions, they provide other important benefits such as enhancement of social and environmental amenity.

To achieve 30% TN reduction, approximately 50% of total stream flows require diversion for treatment and the volume of NUA required will be approximately twice than that required to treat 25% of flows.

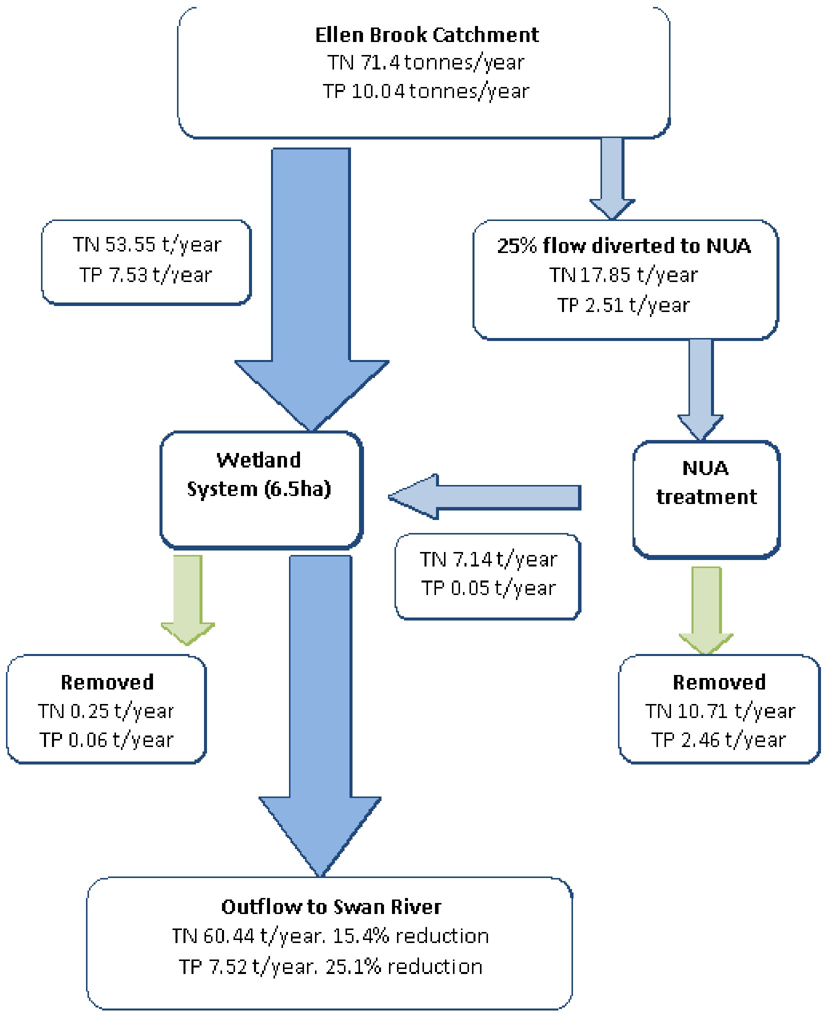


Figure 8 Nutrient balance - treatment of 25% of flows

11.0 CONCEPTUAL OPTIONS

Three concepts were developed for this feasibility study. These concepts reflect the Opportunities and Constraints analysis presented in section 8.0, the Design Criteria and Approach presented in section 9.0 and the Water Quantity and Quality Modelling presented in section 10.0. In line with the feasibility study scope of works, and as discussed in section 10.2, these concepts utilise NUA blend media and wetlands. Concept 1 utilises the NUA blend and wetlands in a passive (gravity) configuration, whilst Concept 2 presents an active (pumping configuration. Concept 3 presents a combined passive/active configuration.

11.1 CONCEPT 1: PASSIVE CONFIGURATION

11.1.1 System Description

Concept 1 proposes a fully passive treatment system utilising wetlands and NUA infiltration areas (refer section 1.1.1 for illustration). The wetlands provide 50 ML of storage and control the delivery of Ellen Brook flows to an infiltration trench system. NUA blends will be contained within the trench system in geo-bags to allow for easy maintenance and removal. Water that has entered and/or infiltrated through the trench is released to a secondary wetland (via overland flow or subsoil drainage) for polishing prior to flowing back into Ellen Brook.

There are opportunities to utilise the trench system as public pedestrian pathways and interpretive trails during no or low flow periods.

11.1.2 Assumptions

Concept one includes the following assumptions:

1. The NUA blend has a saturated hydraulic conductivity of 324 mm/hr. The saturated hydraulic conductivity is based on laboratory testing undertaken by Wendling *et al* 2009 (refer Table 9). Note that the hydraulic conductivity of the preferred NUA blend needs to be determined to more accurately model the passive treatment system. Based on the following potential blend materials, the final hydraulic conductivity may vary significantly. From Wendling *et al* (2009) the hydraulic conductivity of potential blend materials are; Bassendean Sand 540 mm/hr, Steelmaking by-product (SS) 1194 mm/hr, Red Mud (RM) 1188 mm/hr, Red Sand (RS) 2400 mm/hr and Reduced Red Sand (RRS) 768 mm/hr. Additionally, a correction or moderation factor may need to be applied to the laboratory hydraulic conductivity test results to translate them to the larger final site application.

2. Ellen Brook water needs to be in contact with the NUA blend for a minimum of one (1) hour to achieve the nutrient load reductions discussed in section 10.2.

3. The filter depth of the NUA blend is estimated as 280 mm (i.e. the geobags have a 280 mm depth) and the NUA blend is assumed to be homogenously distributed through the bags. This is based on 1 hour contact time at the saturated hydraulic conductivity and assuming Darcy’s flux velocity. Note that the actual flow rate through

the media will vary in a gravity system due to variations in the depth of water ponding (pressure head) above the filtration media.

4. The ponding (extended detention) above the NUA blend trench is assumed as 250mm. This is an assumed average maximum ponding depth over the length of the infiltration trench. It should be noted that any increase in the depth of the media due to an increased contact time, for example, would result in either a larger filter area being required or an increase in the ponding depth.

5. The wetlands provide 50 ML of storage

11.1.3 System Requirements

Darcy's Law has been used to estimate the volume of NUA media required for the average daily diversion flow rate (m^3/s). Darcy's Law is as follows:

$$Q_{max} = k\ x\ Area\ x\ {}^{h_{max}}/_{d}$$

Where;

Q_{max} = the pumped flow rate (m^3/s) or maximum infiltration rate required
Area = length x width of filter
k = the saturated hydraulic conductivity (m/s)
h_{max} = maximum depth of pondage above NUA filter (m assumed to be 0.25m for the passive system)
d = the depth of filter media (m)

In the above equation, the flow rate (Q), hydraulic conductivity (k) and the length (L) of the filter are all constants and therefore the equation can be arranged to relate the filter width, filter depth and ponding depth (h). Contact time is estimated based on the Darcy's flux velocity.

Using Darcy's Law the estimated <u>volume of NUA required for the passive system with 1 hour contact time is 2160 m³.</u> This volume could be located in Site 1 as an 800 m long trench, 0.28 m deep by 9.5 m wide. Extension of the trench system into Site 2 would reduce the required width. Assuming that Site 2 has the capacity to accommodate an additional 800 metres, the trench width could be reduced to 4.75 metres. This width will accommodate both vehicular and pedestrian access.

The volume of filter media is proportionally related to the required contact time and flow rate and therefore confirmation of the required contact time is critical in determining the volume of filter media. Additional calculations using Darcy's Law were conducted to estimate different contact times and their impact on the volume of NUA required utilising a passive system. Figure 9 shows the outcome of this. Importantly, what is shown is that an increase in required contact time correlates with an increase in the required volume of NUA media to treat the required flow rate.

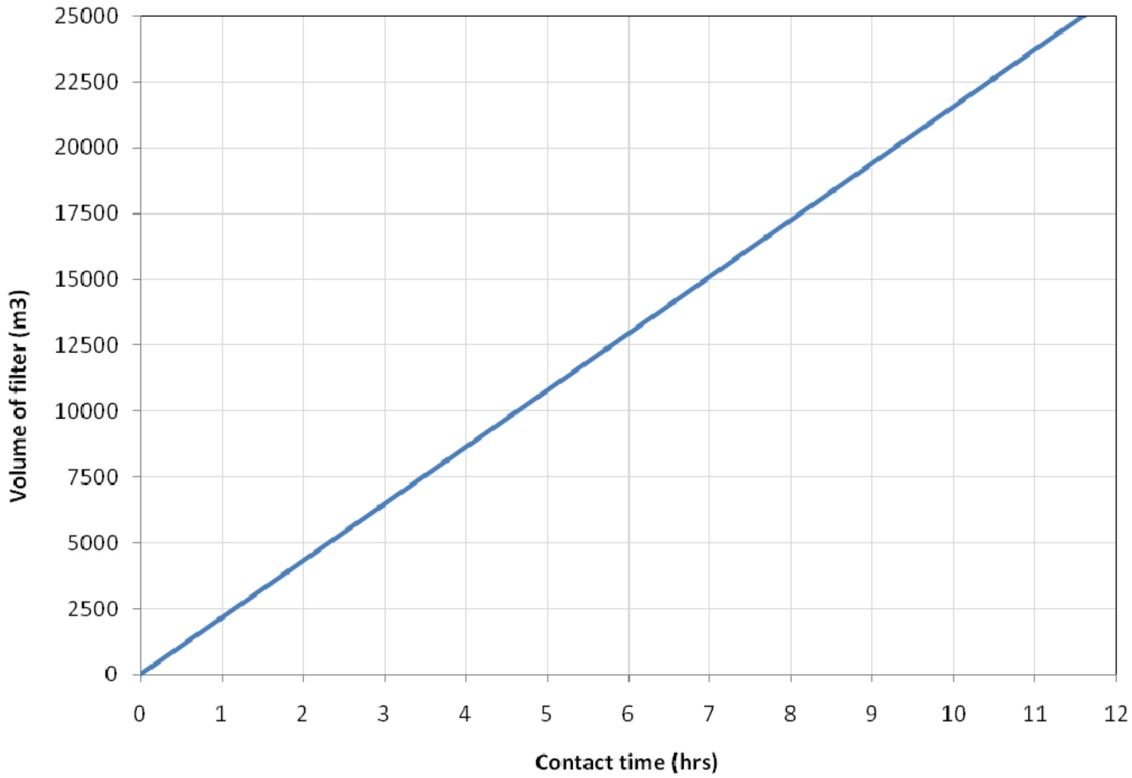


Figure 9 Required volume of NUA for different contact times assuming a passive system

The general arrangement of the wetland system will allow the diversion of water from Ellen Brook into offline wetlands using diversion structures. The details of the diversion structure are yet to be determined. The offline wetlands will release water via an outlet riser by gravity to the head of the infiltration trench at a flow rate equivalent to the flow diversion rate. The surface of the infiltration trench will grade at a minimum gradient in the downstream direction of Ellen Brook to enable flows to be distributed along its entire length. An average extended detention depth over the length of the trench will be maintained by a single or multiple weirs/check dams.

11.1.4 Advantages and constraints

The following advantages and constraints were identified for Concept 1:

Advantages	Constraints
▪ Retains existing Ellen Brook channel ▪ NUA blend media contained in geo-bags for easy removal, replacement and containment ▪ Can be extended to Site 2 and other sites within the catchment ▪ Gravity fed system – no energy requirement, no GHG release ▪ Social opportunities – implementation of trails and interpretation/signage/educational elements ▪ Likely to achieve TN and TP 30% load reduction targets if implemented in a number of locations throughout the catchment	▪ Modification of the existing floodplain ▪ Difficult to control flows and infiltration rates within NUA trench ▪ Replacement of geo-bags is limited to low/no flow periods ▪ Replacement of geo-bags will require vehicular access into the floodplain ▪ Difficult to maintain/ensure homogeneity of NUA blend in bags ▪ Difficult to adjust detention depth over filter

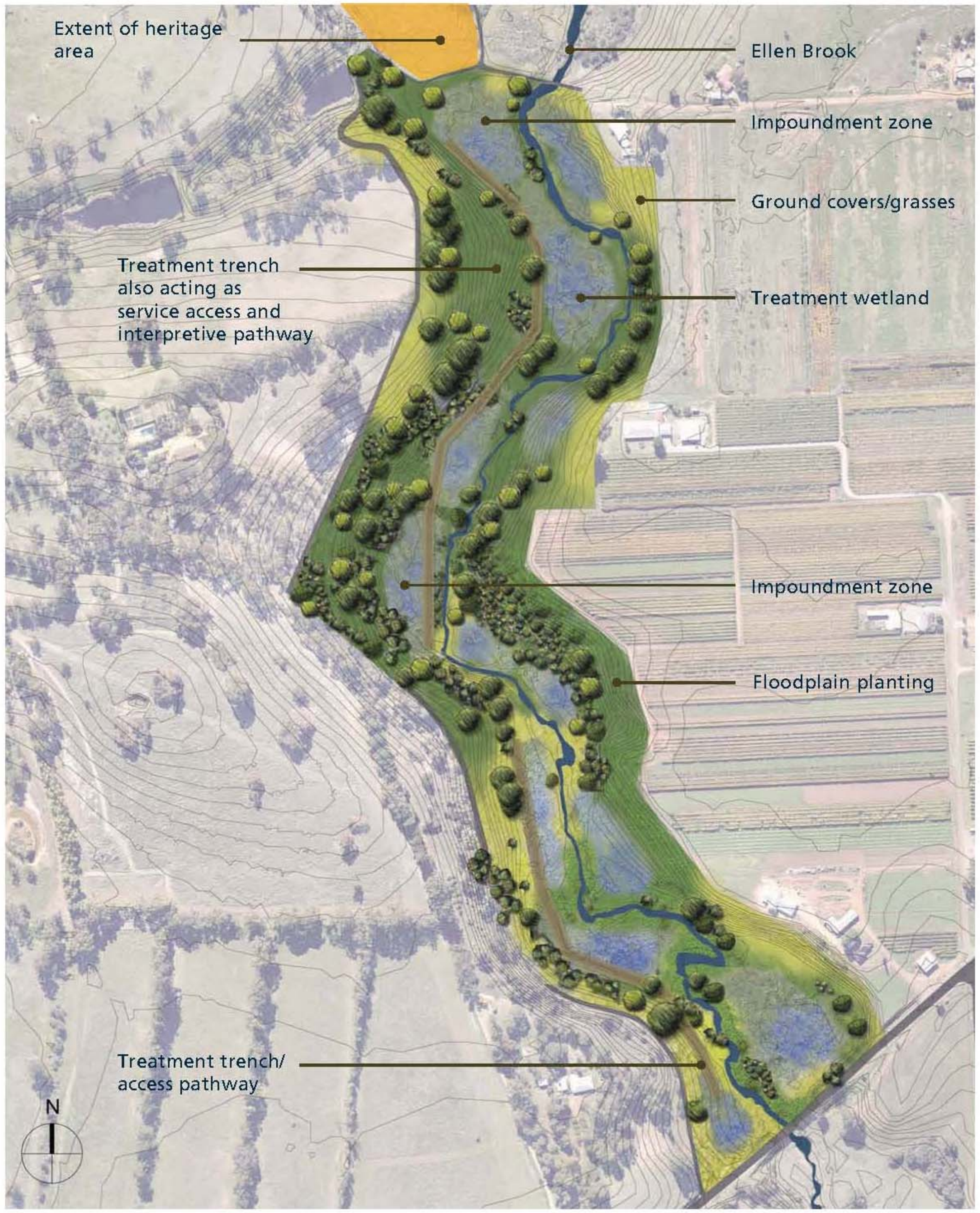
11.1.5 System Illustration

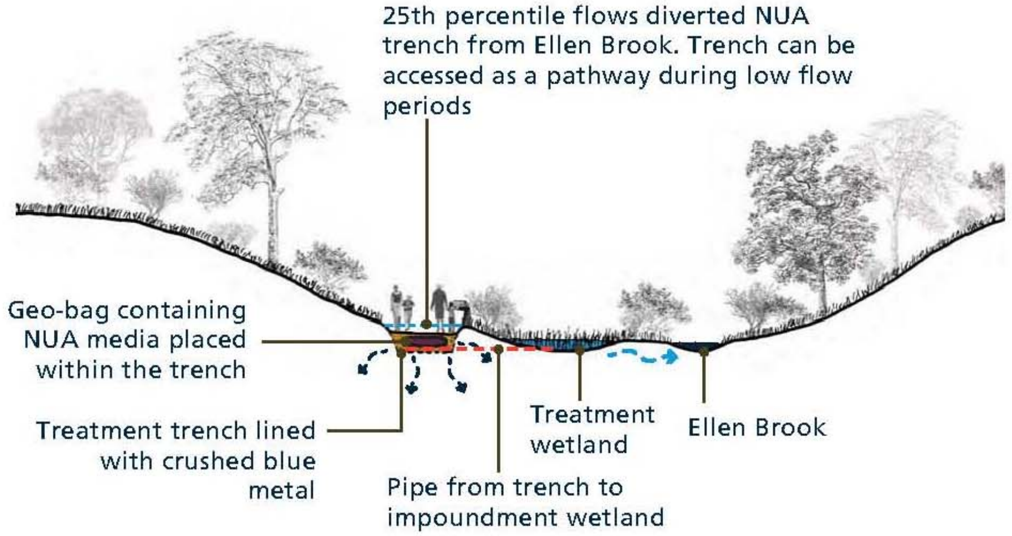
Concept 1 - Passive treatment system

Offline wetlands and NUA trench

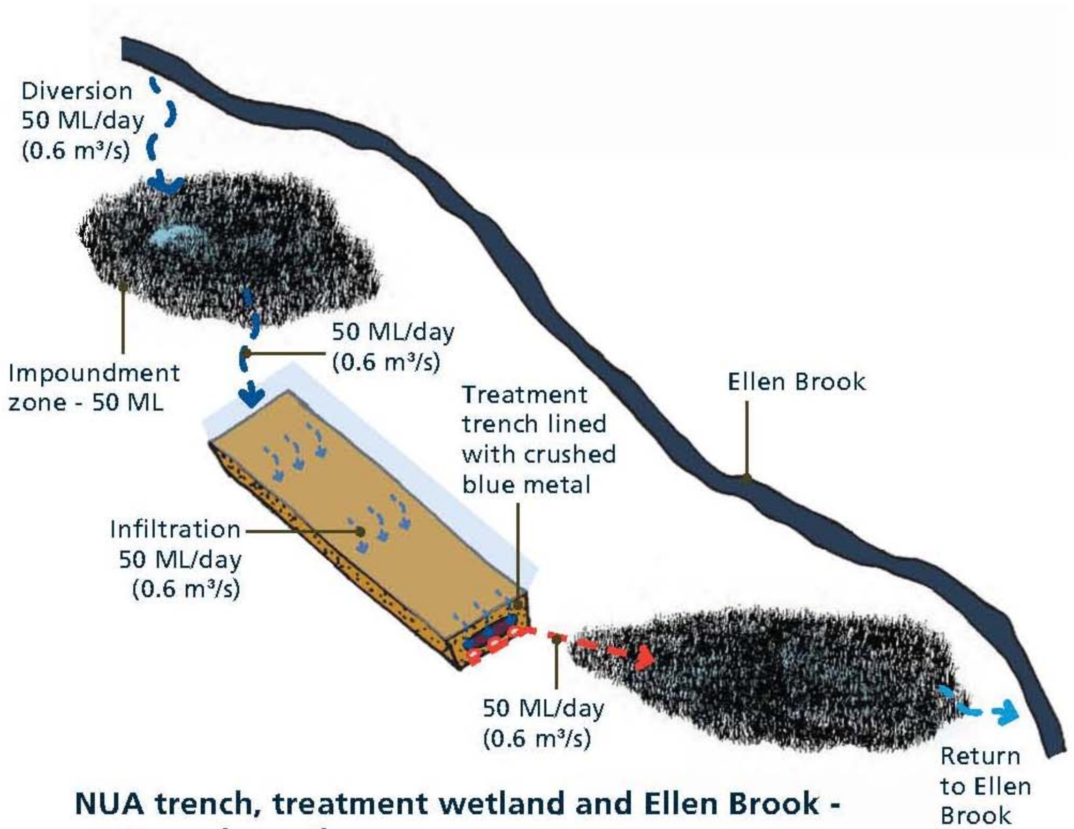
SYRINX environmental pl

© November 2010





NUA trench, treatment wetland and Ellen Brook typical cross-section



NUA trench, treatment wetland and Ellen Brook - system schematic

11.2 CONCEPT 2: ACTIVE CONFIGURATION

11.2.1 System Description

Concept 2 proposes to intercept and store Ellen Brook flows within storage systems that have an effective storage depth of 1.5 m and total storage capacity of 50 ML (refer section 11.2.5 for illustration). Water impounded within this storage system will be actively pumped through NUA blend treatment systems located within the embankment of Site 1. The treated flows are then directed to offline wetlands for polishing prior to re-entering Ellen Brook.

11.2.2 Assumptions

Concept two includes the following assumptions:

1. The NUA blend has a saturated hydraulic conductivity of 324 mm/hr.
2. Ellen Brook water needs to be in contact with the NUA blend for a minimum of one (1) hour to achieve the nutrient load reductions discussed in section 10.2.
3. Storage capacity is set at 50 ML.

11.2.3 System Requirements

As with Concept 1, Darcy's Law was used to estimate the volume of NUA media required for a particular pump rate. The pump rate is assumed to equal the diversion rate of $0.6m^3/s$ to enable the treatment of 50 ML of water over a 24 hour period.

As the assumptions are consistent across Concept 1 and Concept 2, the output of Darcy's Law again indicates that the volume of NUA required for the active system is 2160 m^3 for 1 hour contact time. It is recommended that this volume of NUA is accommodated for within contained treatment systems within Site 1. The dimensions of the treatment system are undefined and can be adjusted to equate to the total volume required for 1 hour contact time using the relationship between velocity and depth in Darcy's Law.

The volume of material will remain constant for the given treatment flow rate while the pressure head, filter area, filter depth and contact time can be varied but are all inter-related (refer Figure 10). For example, decreasing the filter surface area will result in an increase in the required pressure head. Increasing the pressure requires the depth to be increased to maintain the flow rate and required contact time.

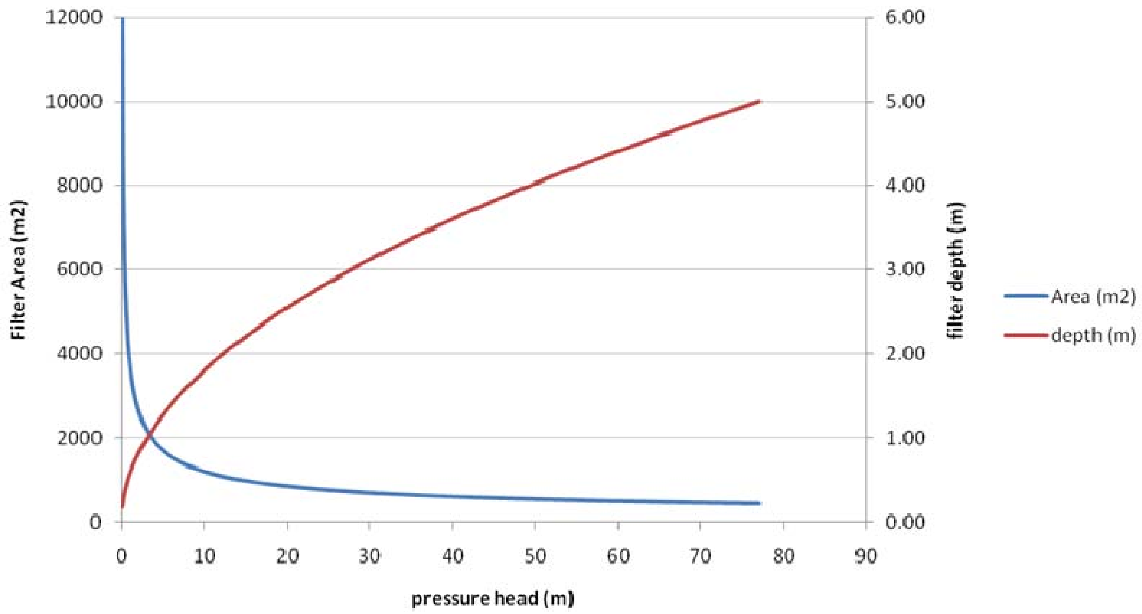


Figure 10 Relationship between pressure head, area and depth (for 1 hr contact)

The energy use associated with the above system is an important consideration to determine the ongoing costs and long term feasibility of the system. Generally, a larger filter surface area will require a lower pressure and result in a lower energy consumption. Conversely, a smaller surface area will require much higher operating pressures and therefore higher energy consumption.

Energy use for the pump system was assessed based on known energy requirements associated with different water treatment facilities (Kenway et. al. 2008). Figure 11 identifies a range of water treatment facilities and the associated energy requirements (MWh) versus volume of water treated (ML).

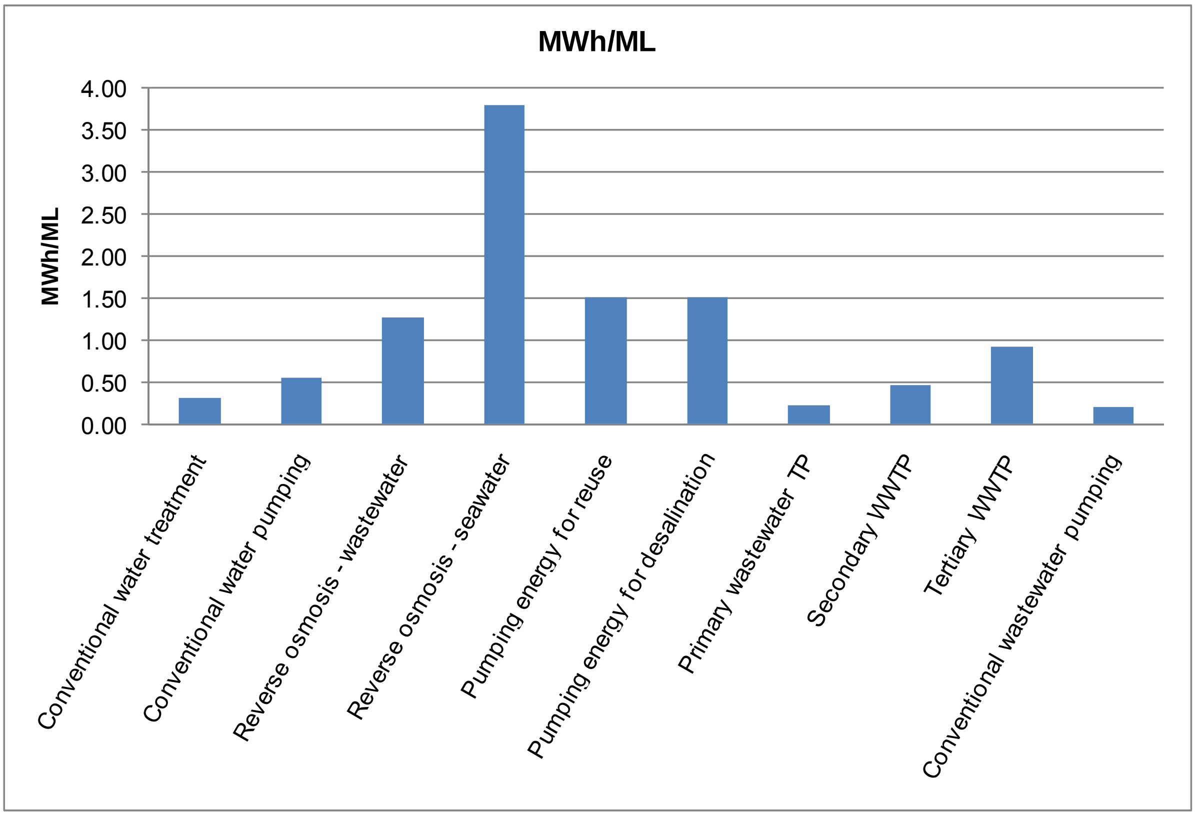


Figure 11 Typical energy requirements of different water treatment facilities

Based on the above typical energy requirements, the energy requirements and operating cost of the NUA treatment system was assessed. Table 14 identifies lower and upper energy requirements and costs. Assuming an energy price of $0.14/kWH (standard domestic electricity price) the lower annual cost to run the system is estimated at $234,500.00 AUD. This is similar to conventional water treatment. The upper annual cost estimate is estimated at $1,407,000.00 AUD. This is similar to pumping energy for desalination. Note that these costs do not take into account future price increases to energy nor do they consider GHG release or the economic benefits of nutrient removal.

Table 14 Annual energy requirements and costs for treatment of 25% (6.7 GL) of flows

Treatable flows	Energy required (lower, 0.25 MWh/ML)	Energy required (upper estimate, 1.5 MWh/ML)	Cost $AUD (lower estimate)	Cost $AUD (upper estimate)
6700 ML/year	1675 MWh/year	10,050 MWh/year	$234,500	$1,407,000

11.2.4 Advantages and constraints

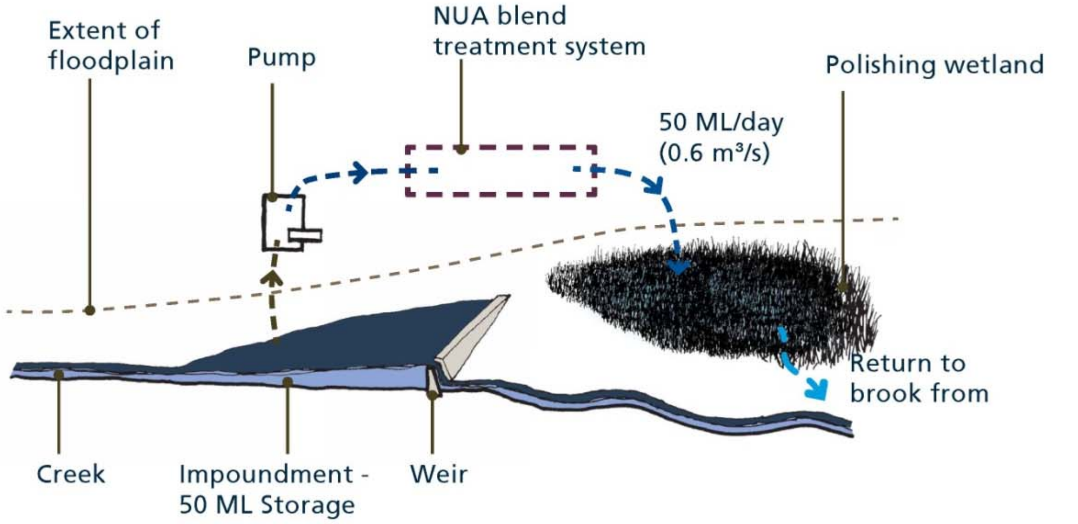
Based on the above preliminary assessments and consideration of other potential impacts, the following advantages and constraints were identified for Concept 2:

Advantages	Constraints
▪ Flow volumes and velocities through NUA can be controlled ▪ NUA is contained and system can be disengaged if necessary ▪ Provision of the weir and storage system will lower the pumping requirements as opposed to pumping flows without storage ▪ Easier to regulate the flow and alter the contact time and pressure head ▪ **Likely to meet TN and TP load reduction aims**	▪ Modifications to existing channel (habitat and morphology alteration) ▪ Alteration of environmental flows (impacts on EWRs) ▪ Fish passage and migration will need to be addressed through fish ladders and other structures ▪ High operation costs due to energy consumption ▪ High maintenance requirements (pump and NUA replacement) ▪ GHG release due to energy consumption/pumping ▪ Can only be replicated in similar topographical conditions throughout the catchment

11.2.5 System Illustration

Concept 2 - Active treatment system

Weirs and NUA treatment system



Storage dam and active treatment system schematic

11.3 CONCEPT 3: COMBINED SYSTEM

11.3.1 System Description

Concept 3 proposes a combined passive and active NUA treatment system as illustrated in section 11.3.5. As with Concept 1, the passive component comprises of wetlands with 25 ML of storage and a treatment trench comprising of NUA filled geo-bags. The wetlands and trenches are sized to treat 15% of total annual flows, particularly low flows during June, July and October. It is difficult to predict how the system will function during higher flow months (i.e. August and September) as the trench and wetland storage are likely to become completely submerged at times. Therefore, higher flows, predominantly during August and September, will be treated via an active NUA treatment system which will utilise an in-stream intake pump system that will capture 10% of total annual stream flows. The active treatment system arrangement differs from Concept 2 as it is treating the high flows only and as such does not require a storage area.

11.3.2 Assumptions

Concept 3 has the following assumptions:

1. The NUA blend has a saturated hydraulic conductivity of 324 mm/hr.

2. Ellen Brook water needs to be in contact with the NUA blend for a minimum of one (1) hour to achieve the nutrient load reductions discussed in section 10.2.

3. 15% of total stream flows are treated with a passive system and 10% of total flows are treated with an active system

4. The filter depth of the NUA blend is estimated as 280 mm (i.e. the geobags have a 280 mm depth) and the NUA blend is assumed to be homogenously distributed through the bags.

5. The ponding (extended detention) above the NUA passive system is assumed as 250 mm.

6. Wetland storage capacity is set at 25 ML.

7. Minimum capture efficiency (percent of flows actually pumped to treatment divided by total flows potentially pumped) for pumping directly from Ellen Brook is assumed to be 15%. The capture efficiency will be determined by the configuration of the off-take within the stream. The off-take will need to be able to facilitate variations in water level and flow rate.

8. Minimum daily stream flow required for pump activation is 50 ML/day

11.3.3 System Requirements

The passive component of the system is required to capture and treat 15% of total stream flows. Using Darcy's Law the estimated volume of NUA required for the passive system with 1 hour contact time is 1,080 m^3. This volume could be located in Site 1 as a 800 m long trench, 0.28 m deep by 4.75 m wide (i.e. half the width of Concept 1). The wetlands require a storage volume of 25 ML which will store 24 hours of flow during June, July and October. The general arrangement of the wetland system will be as per Concept 1, with diversion of Ellen Brook flows into offline wetlands. The wetlands will release water via an outlet riser to the infiltration trench at a flow rate of 0.3 m^3/s.

The active component of the system is required to capture and treat 10% of total stream flows. A minimum stream flow requirement of 50 ML/day is assumed for pump activation. The total flows above 50 ML/day are approximately 20 GL/year or 75% of total annual flows. A capture efficiency of 15% means that up to 3 GL/year can be captured for treatment. The volume of NUA required for the active treatment system is determined by the maximum treatable flow rate and required contact time. With 1 hour contact time the volume required is estimated to be 4,680 m^3. This volume would be located within a contained treatment system within Site 1. The dimensions of the treatment system are currently undefined and will require further development in Stage 2 of the project. A pump intake located above the bed of the brook will deliver flows to the treatment system at a maximum rate of 1.3 m^3/s, predominantly during August and September. The pump rate will be more variable than Concept 2 and is estimated to operate in the range of 0.6 – 1.3 m^3/s. When compared with Concept 2, this approach requires a higher maximum pumping rate (an increase from 0.6 m^3/s to 1.3 m^3/s) and lower number of pumping days (a decrease from 210 days to 94 days). Based on typical energy requirements, the energy requirement and operating cost of the above pumping requirements were estimated at 1.0 – 2.0 MWh/ML or 2,700 – 5,400 MWh/year. This translates to between $378,000 and $758,000 p,a.

11.3.4 Advantages and constraints

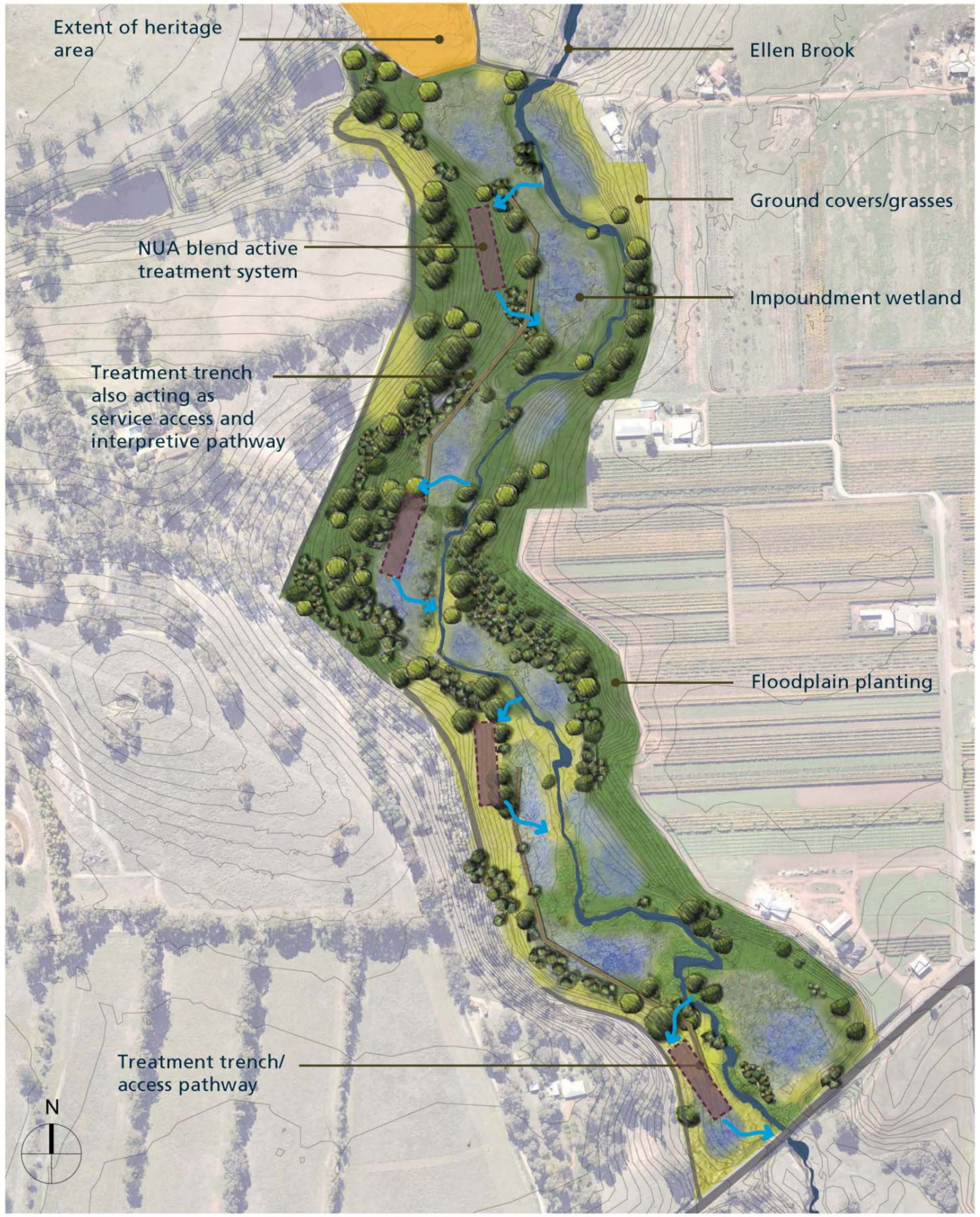
Advantages	Constraints
▪ Retains existing Ellen Brook channel ▪ Both active and passive components can easily be replicated at other sites ▪ Allows social opportunities - walking trails etc during low flows ▪ Treatment during June, July and October	▪ Modification of the existing floodplain ▪ Difficult to control flows and infiltration rates within NUA trench ▪ Difficult to maintain/ensure homogeneity of NUA blend in bags and replace/maintain during high flow

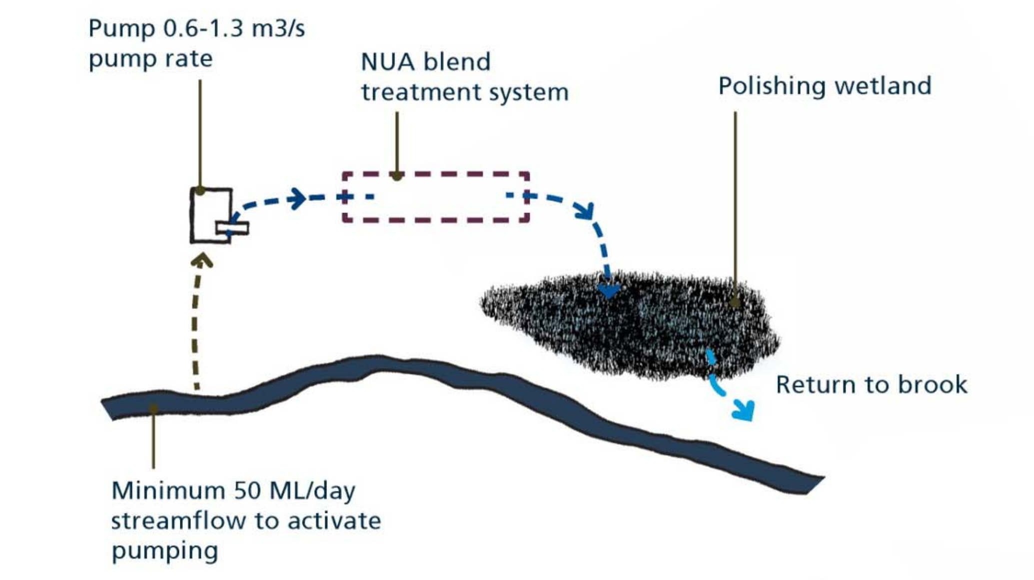
will have no energy requirement, no GHG release ▪ Active arrangement allows control of flow volume and velocity through active treatment system ▪ **Likely to meet TN and TP load reduction aims**	periods ▪ Capture efficiency is unknown for pump component of the active system ▪ Treatment predominantly during August and September will have high operation costs due to energy consumption and result in GHG release ▪ Maintenance of pump system will need to be addressed

11.3.5 Illustration

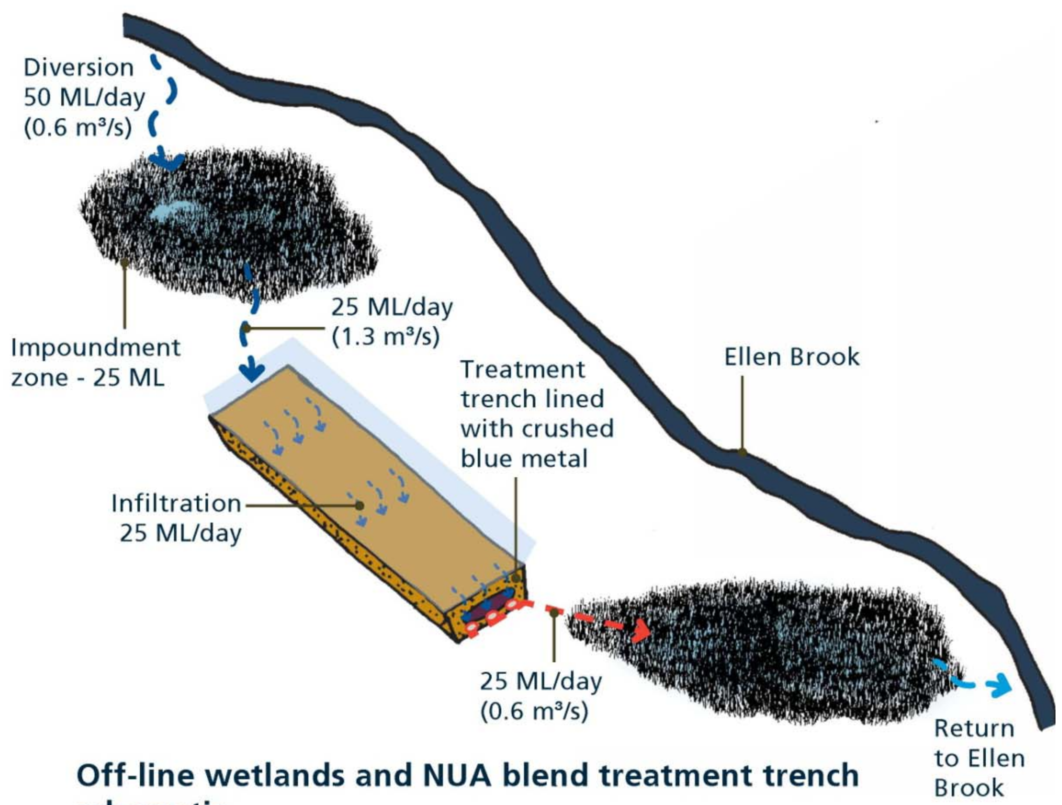
Concept 3 - Combined treatment system

Offline wetlands with NUA blend trench and active NUA treatment system





Storage dam and active treatment system schematic



Off-line wetlands and NUA blend treatment trench schematic

11.4 CONCEPT DEVELOPMENT

Development of the above concepts will require the fulfilment of data gaps identified in section 6.0. In general, the most critical data gaps include the contact time and hydraulic conductivity of the preferred NUA blend. This study has assumed a fixed contact time and hydraulic conductivity as detailed in section 11.1.2 an 11.2.2. Changes to these assumptions will inevitably result in changes to the predicted volume of NUA required. If, for example, the contact time required is in fact 12 hours, then more than 25,000 m^3 of NUA would potentially be required.

In addition to these data gaps, it is suggested that further trials are conducted within the current scope of the NUA pilot trial. Suggestions for additional trials are provided in Appendix 1.

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Appendix 1 Pilot study suggestions

The Concepts developed as a part of this feasibility study include both passive and active NUA blend treatment systems. As the focus of the current pilot study is on one type of active treatment configuration, it is suggested that the Trust/CSIRO conduct additional pilot studies that trial passive systems and combined passive/active systems. Note that, due to time constraints, these studies are unlikely to occur during the 2010 pilot study. Therefore, the recommendations presented below should be addressed/trialled prior to full scale implementation.

The current pilot study assesses the practicality and performance of an active NUA blend treatment system. In this study, the NUA blend is placed in a pipe that is arranged on an incline (preferably 90 degrees). Water is actively pumped vertically from the bottom of the pipe upwards. This setup aims to circumvent preferential flow paths through the NUA media and ensures even contact time with the NUA blend throughout the column. Whilst this may be the preferred option, it is suggested that a vertical feed trial is also conducted, whereby water is pumped to the top of a pipe (or contained system) and passively filters through the NUA blend. Treated water can then be collected at the base and directed back to the stream/polishing wetlands. This trial would be a useful comparison to the current setup and will allow assessment of the difference in pumping requirements (and ultimately operating cost and associated GHG emissions), they hydraulic conductivity of the NUA blend and the impact of preferential flow paths on treatment removal capacity. A simple vertical feed trial could consist of a 500 mm diameter uPVC pipe filled with NUA blend to a metre high and fed by a pump and distributed pipe system. The length of 500 mm diameter pipe will have to accommodate extended detention of water (i.e. a ponding space prior to infiltration). In this case, a ponding depth of approximately 500 mm is suggested, setting the total pipe length at 1500 mm.

In addition to the above vertical feed system, it is suggested that a fully passive system is trialled. It would be useful to gain an understanding if a passive system is feasible and can be used either alone or in combination with the active systems. Trials of the passive system could consist of geo-bags filled with the NUA blend and placed within a trench system adjacent to the streamflow. The trench system could be arranged in a similar fashion to bioretention system as discussed in the Stormwater Management Manual for Western Australia (DoE, 2004) and WSUD Engineering Procedures (Melbourne Water, 2005). The longitudinal grade of the trench should be minimised to encourage infiltration. A maximum grade of 1% is recommended. The layout will need to allow for the water to pond above the filter to promote infiltration. An extended detention depth of approximately 280 mm is suggested. Sub-soil drainage (100 dia. slotted pipe) graded at a minimum of 1% to the outfall and coarse gravel/sand bedding shall be provided at the base of the system (below the NUA geo-bag). In this case it is suggested that 300 mm depth geo-bags are bedded on 200 mm of gravel/ coarse sand with 100 dia. slotted pipes located in the lower 100 mm of the gravel/sand. In order to ensure the accuracy of the data, it is recommended that the trench is fully lined with

HDPE liner to prevent interaction with groundwater and limit infiltration to site soil. A riser outlet may be required where the pipe is below the water level of the stream. This riser outlet can be combined with an inspection/sampling point to allow for water quantity monitoring and quality sampling. The outlet may require a flap valve to prevent backwash entering the sub-surface drainage system. Once the trench has been constructed, a portion of flows can then be diverted to the trench system.