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Mat Morris

Byron Venue Management Pty Ltd

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Date: 3 October 2018

Ref: 1912 RTC 31018sd

Re: Wastewater Assessment for North Byron Parklands

1. Introduction

At the request of Byron Venue Management Pty Ltd (the Client), Whitehead & Associates (W&A) prepared a Wastewater Assessment (WWA) for the proposed continuation and expansion of the North Byron Parklands (NBP) cultural events site. The WWA (Ref: 1912 WWA 081217 Rev, dated 8 December 2017), was included as Appendix R in the Environmental Impact Statement for the proposed development.

A number of comments were received on the WWA by the Department of Planning & Environment (DP&E) appointed third party reviewer, GHD[1]. The WWA was revised and reissued on 9 July 2018, and final comments were received by GHD[2] in late September 2018.

A summary of the GHD comments are addressed in Table 1 below.

Table 1: Further Information

Item	DP&E Comment	Response
1	GHD raise the low wastewater gen rates for the festivals generally and for the conference centre specifically.	The festivals have been operating for a number of years now and have good operational data upon which to base the concept design. The conference centre wastewater production was based on published AS/NZS1547:2012 flow allowance data, modified for compost systems. The assumed wastewater production data are considered realistic. It must be borne in mind that:

[1] North Byron Parklands Development Application Wastewater Review. April 2018. 2316318

[2] North Byron Parklands Wastewater management Review of additional information. September 2018. 2316318

Item	DP&E **Comment**	Response
		1. The daily peak flows of the conference centre would be about 16kL/day, small compared to the 1ML produced during a major festival; and 2. Flow meters and monitoring is proposed for the treatment system, so the operator will be able to monitor influent rates and make ongoing management decisions based on that information.
2	The staged upgrade of the WW treatment system is problematic.	The concept WWA prepared by W&A did not allow for staged upgrade of the WW treatment system. The treatment system of flow balancing tanks, holding tanks, septic tanks, reed beds and disinfection/irrigation tanks were proposed to be installed in one construction phase during Stage 1 of the NBP masterplan. The system would be oversized and provide redundancy in the treatment train as the activities at NBP grow to Stages 2 and 3. It was proposed to install the supporting rising main lines progressively, such that ongoing vacuum truck cartage of wastewater from the festival amenities would be phased out and automated. The rising main from the conference centre would be installed during construction of that facility. The use of vacuum trucks to cart wastewater from the amenities to the holding tanks has been occurring for a number of years now with no known environmental or human health issues recorded. The use of vacuum trucks also provide redundancy and flexibility in the transport system in that the “pump” unit is not fixed but mobile.
3	Continued burial of compost on the property poses health and environmental risks.	There is an existing s68 approval for burial of compost on the Site. This has been operating for a number of years for the festival site with no known side effects. As detailed in the WWA, the proposed ongoing burial of compost is to include a formalised management plan that implements a testing regime to confirm suitability for burial, and if not suitable then the requirements for ongoing maturation. There is ample area at the NBP site for burial of compost. Compost burial is located outside any flooding areas and would not be utilised for tree planting zones without additional treatment and certification.
4	Nutrient buildup in the land application area.	W&A undertook extensive modelling utilising two separate daily water balance models including the QLD Government supported MEDLI model that was designed specifically for large-scale irrigation of wastewater. MEDLI is best practice for irrigation modelling and involves a comprehensive water balance to ensure the design assumptions are achievable. It was shown that the application of treated effluent is sustainable at NBP over at least a 27 year lifecycle for the 3.6Ha irrigation area. The WWA presented additional suitable area of 26Ha that is available for irrigation, which increases the lifespan of the land application for nutrients to 200 years. All land application systems for wastewater have a nutrient buildup lifecycle. It is an assumed condition for approval of the OSMS. The actual lifespan of an OSMS can be increased by reducing the nutrient (N & P) concentrations in the wastewater and/or increasing the footprint. It

Item	DP&E **Comment**	**Response**
		has been shown that the footprint of the land application can be increased. In addition, the WWA recommended at least annual monitoring of effluent quality, such that if output quality is not being met then adjustments to wastewater processing could be made.
5	Use of flood prone land for land application	The irrigation modelling using MEDLI accounted for daily weather conditions, such that periods of no irrigation were allowed for. It is expected that during dry periods where water tables are low at 0.6-1.5m depth then irrigation could occur at higher rates than the minimum suggested by the model such that additional wet weather/flood storage capability is available for wet weather contingency. The application of irrigated wastewater on the extensive flat grassed northern portion of the NBP was considered appropriate by W&A as this area is located in an environmentally less sensitive location with extensive farmland down gradient to the north, no significant waterways in the vicinity, good drainage ability in the underlying sands, safety and ease of land application, and robust application method.
6	Continued transport of kitchen sullage to Byron and Ballina STP	The WWA stated that kitchen sullage would be transported to Summerland waste facility, a private waste management facility. No sullage would be transported to Byron or Ballina STP. An agreement is in place until the construction of the upgraded OSMS for acceptance of portaloo, shower greywater and laundry greywater from the non-amenities zones at the two major festivals.
7	S3.3.4 The treatment efficacy of the design based on the input chemistry	The WWA utilised the chemical quality of the actual wastewater in the holding tanks based on 4 years of collected data, which was utilised in the modelling (column 10 in Table 16 of the WWA). Some of these parameters (and particularly for nitrogen) are higher than domestic strength effluent. The use of the term greywater in the WMA report was merely an ongoing use of the general term adopted by NBP to describe the existing OSMS, rather than a definition upon which to rely on modelling and treatment efficacy. Table 2 of S3.4 of the GHD final review erroneously suggested that the original WWA allowed for 244m² reed bed area. Table 17 of the original WWA (December 2017) allowed for 400m² (600m³) of reed bed. Given the focus on the reed bed efficacy, NBP engaged a third party technical expert on reed beds and wetland systems, Dr T. Headley of Wetland and Ecological Treatment Systems. Dr Headley was part of the pioneering scientific research and experimentation of reed beds and wetlands in northern NSW and has co-authored numerous papers on the subject. Dr Headley's review of the WWA (attached) confirms that: 1. It is possible to treat the chemistry specific, high N wastewater at NBP using a passive ecological treatment system; 2. For the current horizontal flow passive reed bed design, utilising a P-k-C* model (rather than the earlier K-C* model that was utilised in the WWA), outputs from the treatment system of BOD ≤9mg/L, TSS <5mg/L, TN ≤48mg/L and TP ≤16mg/L is realistic within a reed bed area of 2,100m² (1260m³);

Item	DP&E Comment	Response
		3. That an alternative design incorporating septic tanks, a 400m² vertical flow wetland including 50% recirculation, and a final denitrifying bioreactor would achieve the output TN of 48mg/L modelled by W&A. A number of case studies were provided of actual treatment systems in operation including: - Shearwater School (high N), ~2.5kL/day reed bed; - Cape Byron School (high N), ~2.5kL/day reed bed; - Bau Farm Nursery (high N and P), 125,000kL/day reed bed with irrigation reuse; - Jubullum Aboriginal Community, 35kL/day, using a mixed septic tank, horizontal wetland, facultative pond and horizontal subsurface wetland; - Modanville General Store, 1.1kL/day, using a mixed septic tank, vertical wetland and horizontal wetland; - Sundrop Farms, 22,000kL/day, using a mixed septic tank, vertical wetland; - Al Fuhais (Jordan), 1,000kL/day, using a septic tank followed by vertical wetland The revised reed bed sizing of 2,100m² has been adopted for NBP and represents an area increase of 450% (and volume increase of 250%). The sizing difference primarily relates to the ability of the horizontal flow reed bed to process the high N wastewater, and additional unpublished coefficient values that Dr Headley has available for such specific conditions. The attached Figure 9, and Graph 1 below, present the revised conceptual treatment train and layout for the OSMS at NBP. As indicated in Figure 9, the increased reed bed size is able to be accommodated within the proposed wastewater treatment plant area without the need for any additional vegetation clearing or significant expansion of the treatment system area. Further engineering design of the OSMS is required for s68 approval; and use of recirculation and bioreactors will be considered at that time to maximise the design potential.
8	S6 Regulations and Standards. Suggested that the OSMS would be considered "effluent recycling", and that the output quality should be BOD <20mg/L, TSS <30mg/L, Faecal coliforms <1000cfu/100ml. Nutrient quality outputs of TN <40mg/L and TP <7mg/L were also suggested but	Wastewater is being generated onsite and will remain onsite. As such the OSMS does not fall under the "Australian Guidelines for Water Recycling", the NSW DPI Recycled Water Management Systems, or the NSW DEC Use of Effluent for Irrigation. All these guidelines refer to wastewater generation on one property, and its beneficial reuse on another property such as for golf course irrigation, horticulture etc. It is our view that generation of wastewater and land application of treated effluent on the NBP (at allowable rates), whether by subsurface or surface means, is permissible under the NSW LG Regulation and Act. Surface irrigation of secondary treated effluent is allowed as long as the parameters meet the 20/30/30 rule (see table below).

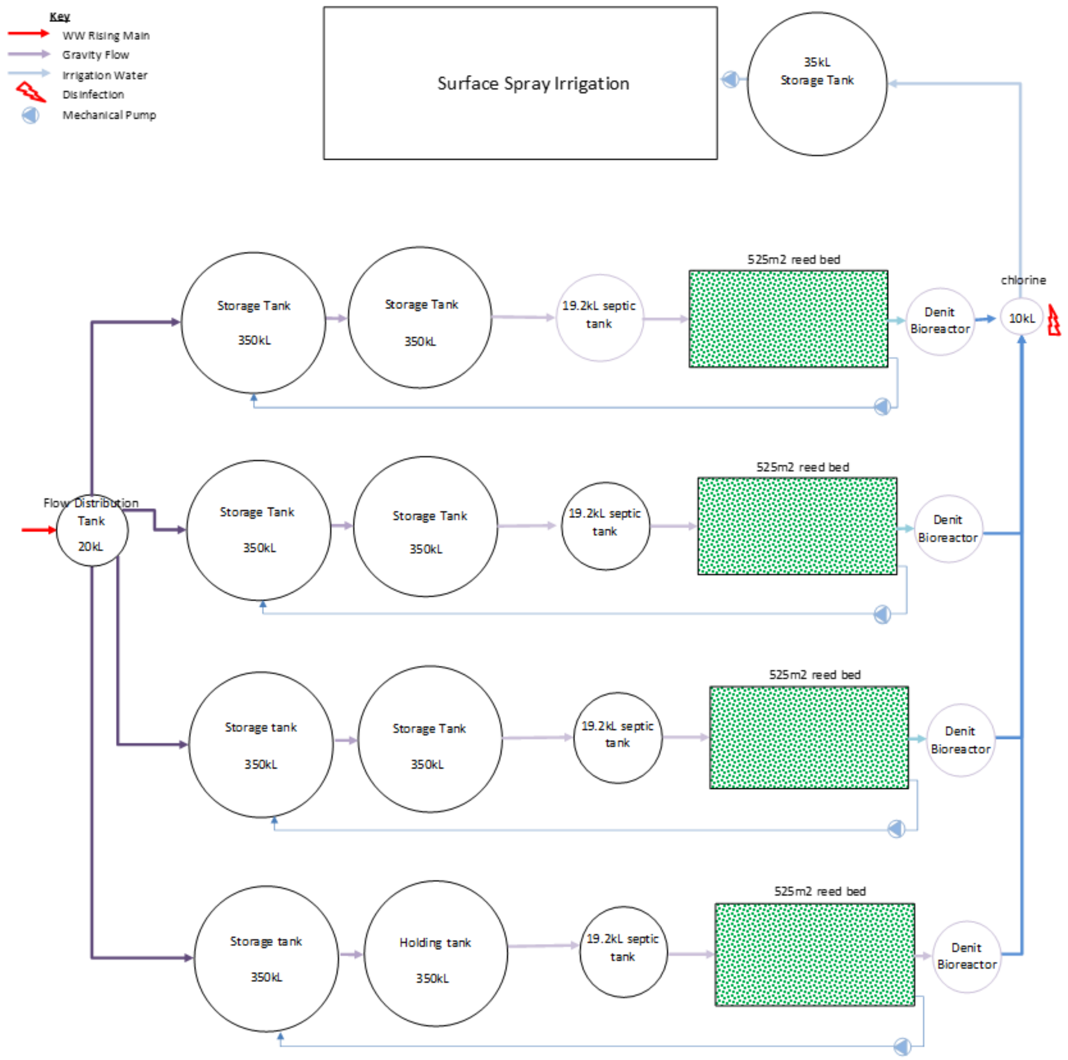
Item	DP&E Comment	Response
	acknowledged to be dependent on the land being applied.	As acknowledged by GHD, nutrients outputs are site-specific based on suitability, and the TN and TP values suggested by GHD have no basis in guidelines or standards. Extensive modelling using the MEDLI program was undertaken by W&A which confirmed that sustainable effluent irrigation could be achieved over a 36,000m^2 footprint at TN and TP quality of 48mg/L and 19.8mg/L respectively. The revised reed bed conservative design would reduce TP output to at least 16mg/L, which would further improve the sustainability of the system. It is suspected that given the residence time within the holding tanks (and sedimentation effects in TP removal) which were conservatively not factored in by W&A, the actual P outputs will be lower than that modelled.

Parameter	Allowed Input to Septic (mg/L)	Septic Effluent (mg/L)	WWA OSMS Output (mg/L)	Secondary Standard (1)	NSW DEC 2004 (2)	NSW DEC 2004 (3)	Dr Headley Modelled Output
BOD	450	150	8	20	40	1500	9
SS	150	26	3	30			<5
TN	380	190	48	-	50	100	48
TP	38	22.8	19.8	-	10	20	16
FC prior to disinfection	1x10^7	1x10^5	1x10^2	1x10^3 - 1x10^4	-	-	<1x10^3
FC post disinfection	-	-	30/100ml	30/100ml	-	-	-
RB Volume	-	-	700m^3	-	-	-	1680m^3
RB Size	-	-	466m^2	-	-	-	2100m^2

1. NSW Health definition in advisory note 4 (2012)
2. Low Strength irrigation water
3. Medium Strength irrigation water

Item	DP&E Comment	Response
9	Concerns about the storage of wastewater in tanks prior to treatment	W&A note that: 1. This method has been utilised for the festivals for the previous 4 years with no human health or environmental issues. The storage tanks are located in a remote location on the property, with no known previous odour complaints. 2. The downslope property to the north is owned by the same company and is not in an environmentally sensitive location. 3. Further engineering design of the treatment system is required, and this may include the construction of bunding in case of minor leakage. 4. The storage of raw wastewater for months is undertaken daily around the world at Council Municipal STPs in open facultative pond treatment systems, where raw wastewater is entirely open air treated. The proposed treatment system is “contained” rather than open air as in facultative ponds in both the storage and septic tank stages, and the reed beds operate with a maximum operating height such that there is a minimum gravel covering at all times to limit disease vectors forming.
10	Concerns about chlorine disinfection as an environmental issue.	The focus on nutrient reduction in the reed bed design is such that the revised hydraulic residence time is longer than typically required for reed beds. The result is that the BOD and TSS outputs will be at concentrations well below that required for successful secondary treatment and disinfection (BOD <9mg/L v required min 20mg/L, and SS <5mg/L v required <30mg/L). As such the effluent

Item	DP&E Comment	Response
		clarity will be very good, which will result in excellent disinfection ability with chlorine. Chlorine disinfection is an industry standard for disinfection of treated effluent. There are other methods for effluent disinfection but all have their strengths and weaknesses. Chlorine was recommended as it is robust and simple to administer, and given appropriate management of residual chlorine at 0.2-2mg/L has been utilised successfully for many years in Australia with no significant environmental effects.



Graph 1 (From Graph 6 of WWA): Revised Schematic of NBP OSMS Treatment System for Stage 3.

For and on behalf of

Whitehead & Associates

Strider Duerinckx

Office Manager

Encl WetSystems Technical Memorandum 180921-2 and Case Studies

Figure 9 Recommended NBP Master Treatment System

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Technical Memorandum (#180921-2)

North Byron Parklands

To:	Matt Morris (North Byron Parklands)
From:	Tom Headley
CC:	Strider Duerinckx (Whitehead and Associates)
Date:	28/09/2018
Re:	Review of HSSFW sizing for North Byron Parklands Onsite Sewage Management System

Introduction and Background

This Technical Memo summarises the results of a review of the preliminary sizing and treatment performance predictions for the Horizontal Subsurface Flow Wetland (HSSFW) proposed to provide secondary treatment as part of the On-site Sewage Management System (OSMS) for the North Byron Parklands site.

It is understood that, as part of the EIS process, Whitehead and Associates (W&A) conducted a Wastewater Management Assessment (WMA) including a proposed OSMS for wastewater generated during events held at the site. Wastewater will consist predominantly of greywater, urinal wastewater and leachate from composting toilets, making it relatively high in nitrogen (TKN) and organic matter (BOD) compared to typical domestic wastewater. The proposed OSMS included horizontal subsurface flow wetlands, or reed beds, to provide secondary treatment of the wastewater following primary treatment. The wastewater from events will be stored in large storage tanks with sufficient capacity to enable the wastewater to be gradually bled to the primary treatment tanks and subsequent treatment steps at an average rate of 35 kL/d. The treated effluent is proposed to be disposed of via surface irrigation onto a land application area following chlorine disinfection. Thus, the effluent from the HSSFWs needs to be of good secondary quality to ensure effective disinfection and sustainable irrigation. The degree of nutrient removal is also of importance with regards to the sizing of the land application area.

It is understood that a HSSFW with a residence time of 7 days, wetted depth of 1.5m and a surface area of approximately 500 m^2 was proposed in order to achieve the treatment performance indicated in Table 1.

A review of the proposed solution by GHD has raised questions about the sizing and expected treatment performance of the HSSFWs. Therefore, WET Systems were engaged by North Byron Parklands to provide an independent technical review of the proposed HSSFW design. Dr Tom Headley of WET Systems has over 20 years' experience with constructed wetlands, including extensive research into HSSFWs in the sub-tropical North Rivers Region.

For the purpose of this review, it has been assumed that the influent concentrations shown in Table 1 provide a reasonable representation of the septic tank effluent that will be entering the proposed reed beds. No attempt has been made here to verify the validity of the assumptions behind the predicted wastewater quantity or influent composition, which are beyond the scope of this assessment.

Table 1: Assumed HSSFW influent and effluent concentrations in the WMA

Pollutant	Units	Reed Bed Influent	Reed Bed Effluent
BOD_5	mg/L	150	8
TSS	mg/L	26	3
TN	mg/L	190	48
TP	mg/L	22.8	19.8
Faecal coliforms	cfu/100mL	1×10^5	1×10^2

Methodology and Assumptions

With the exception of TSS, the first order P-k-C* modelling approach presented by Kadlec and Wallace (2009) was used to assess contaminant concentration reduction versus wetland size for given inflow scenarios. For TSS, the regression equation given by Crites *et al*. (2006) was used, which relates effluent TSS to the influent concentration and hydraulic loading rate.

The P-k-C* model (Equation 1) is the current internationally accepted state-of-the-art approach for constructed wetland sizing. It is worth noting that the PKC* model is an advancement on the KC* model used by W&A in their WMA, because it incorporates the coefficient "*P*" to account for hydraulic inefficiencies and pollutant weathering. The more simplistic KC* model assumes ideal plug flow and was the common approach used before the publishing of the PKC* model in 2009.

The areal form of the P-k-C* equation has been used, as the evidence in the research literature repeatedly indicates that it is the surface area which has a stronger influence over treatment performance in HSSFWs, rather than volume or residence time, especially for oxygen requiring processes such as BOD removal and nitrification. This is primarily because the transfer of oxygen into the system is the rate limiting process, which in a HSSFW is governed by diffusion across the air-water interface and leakage from the wetland plant roots (which tend to occupy the 30 cm of the gravel media), both of which are dependent on the surface area of the wetland rather than its volume. The volumetric form of the KC* model was used by W&A for the reed bed sizing in the WMA, which is acceptable providing the wetted depth of the proposed HSSFW is kept within the range of the systems from which the volumetric *k*-rates used in the model were derived (i.e. 0.4 – 0.6m).

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Technical Memorandum (#180921-2)

The PKC* is a modified first order, tanks-in-series kinetic model developed specifically to describe contaminant concentration reduction in wetland systems as a function of hydraulic loading rate, and therefore wetland area.

$$C_o = C^* + (C_i - C^*)\left[1 + \frac{k}{Pq}\right]^{-P}$$

(Eq. 1)

Where,

C_o = effluent concentration

C_i = influent concentration

C^* = background concentration

k = first-order areal reaction rate coefficient

P = a coefficient reflecting hydraulic efficiency and contaminant weathering

q = hydraulic loading rate (based on average of inflow and outflow rates)

Model parameters for *k*, *P*, and *C** were selected for each contaminant being modelled based on literature values (e.g. Kadlec and Wallace (2009) have calibrated these parameters using data across several hundred HSSFW systems) and my own extensive monitoring data (published and unpublished), including studies of two reed beds treating school greywater (high in nitrogen due to urinal inputs) including compost toilet leachate which are considered to be very relevant to the wastewater characteristics from the North Byron Parklands.

The *k* rate defines the rate of concentration reduction towards the selected value of *C**. The model considers that some contaminants have a background concentration (*C**) above zero in wetland systems due to internal generation processes (e.g. production of organic matter via growth and decay of plant biomass). The k rates were adjusted for temperature in order to evaluate treatment performance during the warmest and coldest months (assuming the mean monthly air temperature for the location provides a reasonable indication of the expected water temperature; given the long storage of the wastewater, this should be reasonable). The model also accounts for hydraulic inefficiencies and non-ideal flow, via adjustment of the *P* coefficient, which is analogous to the number of tanks-in-series as a representation of the degree of internal mixing.

For a given set of influent conditions (flow rate and concentrations), the model can be used to either predict the expected effluent concentrations for a given wetland area, or the required wetland area needed to achieve a pre-defined set of effluent concentrations. Given that the wastewater in question is atypical, particularly due to the high nitrogen concentration relative to the BOD, the resultant mass removal rates from the modelling were cross-checked against literature values to

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make sure they are within the realm of demonstrated experience; if not, the *k* rates were adjusted up or down accordingly.

The hydraulic loading (m/d) rate used in the modelling was based on the average of the design inflow (35 m^3/d) and the estimated outflow from the HSSFWs based on a water balance model. The modelling was conducted for the warmest (January) and coolest (July) months, given that temperature affects the rate of pollution reduction and the water balance also varies seasonally. The water balance model presented by Headley *et al*. (2012) for HSSFWs on the sub-tropical North Coast of NSW was used. Average rainfall data from the Cape Byron lighthouse Bureau of Meteorology (BoM) weather station were used, along with average monthly Class-A Pan Evaporation rates from the Alstonville BoM station and the pan coefficients given in Headley *et al.* (2012) for HSSFWs with established vegetation in January and July. Given the relatively large size of the HSSFW under consideration, consideration of the water balance becomes important.

Results and Observations

A summary of the PkC* parameters used in the HSSFW modelling is given in Table 2.

Table 2: PkC* parameters used for the HSSFW modelling.

Model Parameter	BOD_5	TN	TP	Faecal Coliforms
P	3	6	6	6
k_{20}	0.07 (for >100 mg/L BOD) 0.10 (for <100 mg/L)	0.023	0.005	0.282
C*	5	1	0.0002	0
θ	0.98	1.005	1.0	1.002

A summary of the HSSFW modelling results is provided in Table 3. The modelling indicates that a HSSFW with an area of 2100 m^2 is needed to achieve the effluent quality concentrations proposed in the WMA during both Winter and Summer operation. Regarding the depth of the HSSFW, there is generally little benefit to be gained by making HSSFWs deeper than about 0.8m, because you suffer a reduction in volumetric treatment efficiency is suffered (for oxygen requiring processes) due to a reduction in oxygen transfer into the substrate as it becomes deeper. Consequently, there will be no net saving in surface area as the wetted depth is increased beyond 0.8m (see for example: Headley *et al*., 2005 and Kadlec and Knight, 2009). For these reasons, an areal rather than volumetric approach

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to the sizing of HSSFWs is generally now recommended, in contrast to the earlier recommendations of Headley *et al*., (2003). A HSSFW depth of 0.8m or less is recommended.

Table 3: Summary of the pollutant reduction and water balance modelling for the HSSFW. A wetted depth of 0.8m has been assumed.

Season	Q_{in} (m^3/d)	Q_{out} (m^3/d)	Area (m^2)	HRT (days)	BOD_5 (mg/L)	TSS (mg/L)	TN (mg/L)	TP (mg/L)	*E. coli* (cfu/100mL)
Summer	35	25.2	2100	19.5	**9.0**	**<5**	**45**	**16**	**<1000**
Winter	35	29.5	2100	18.2	**7.7**	**<5**	**48**	**16**	**<1000**

Other Design Considerations

Several options can be considered for this type of wastewater to increase the treatment efficiency of the system and reduce the footprint from the 2100 m^2 HSSFW that is required to achieve the proposed effluent concentrations.

Due to the higher oxygen transfer rates and finer filter media, a Vertical Flow Wetland (VFW) is considered a much more efficient option for removing BOD and TSS, and nitrifying the wastewater (converting the TKN into nitrate), compared to a HSSFW. For example, a very preliminary sizing calculation indicates that a VFW with an area of about 400 m^2 will be capable of achieving the required TSS and BOD concentrations, while removing the majority of organic N and ammonia N. The effluent would still contain approximately 100 mg/L of nitrate-N, of which 50% would need to be removed in order to achieve the effluent TN concentrations proposed in the WMA. Recirculation of the VFW effluent back into the primary treatment tanks, where the BOD and anoxic conditions present will promote denitrification and result in removal of a significant proportion of this nitrate (see for example Al-Zreiqat *et al*., 2018 in which we demonstrated a nitrate removal efficiency of > 83% in recirculating VFWs). A Denitrifying Bioreactor with wood-chip substrate, or a HSSFW with reduced area and wood-chip included in the substrate, could also be used to further remove nitrate in the VFW effluent (see for example: Tanner *et al*., (2012) in which we presented the performance of VFWs followed by Denitrifying Bioreactors for achieving removal of Total N in decentralized systems). Such Denitrifying Bioreactors are increasingly being used for passive nitrate removal in applications such as agricultural runoff, on-site systems and landfill leachates.

Such optimization of the system could be refined through additional design work during the detailed design stage.

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Technical Memorandum (#180921-2)

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If you have any questions, please do not hesitate to contact me.

With kind regards,

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Examples of Relevant Subsurface Flow Constructed Wetlands

1. *Shearwater Steiner School: Treatment of school wastewater (mainly blackwater and urinals) rich in nitrogen*

One of two trains of HSSFWs shortly after planting in 1997.

View of HSSFWs and maturation pond after 1-year operation.

Summary of Key Points from Monitoring

- Intensive monitoring over three seasonal periods (Winter, Spring and Summer)
- Influent rich in TN (100 – 300 mg/L) due to high proportion of urine and blackwater.
- Reed beds achieved 35 – 50% removal of TN and TP at HRT of 7 – 9 days.
- Monitoring included a peak load of >2 x the design capacity during a school Open Day. Influent TSS, BOD, TN, TP and Faecal Coliforms all spiked, with slight increase at outlet. Effluent quality returned to normal within 10 days.
- Robust performance considering highly variable loading situation (wastewater generation only during school hours, no flow on weekends, occasional events with peak loads etc)

Date:	Constructed 1997
Location:	Mullumbimby, NSW, Australia
Role in project:	Monitoring of system during 1st year of operation through Southern Cross University (refer to attached paper: Headley and Davison, 1999). Design review for expansion.
Wastewater type:	School wastewater (toilets, urinals, canteen kitchen)
Capacity	250 students. Average HRT = 9 days (including weekend resting)
Technology used:	Treatment: Septic Tanks → Horizontal Subsurface Flow Wetlands → Maturation Pond Disposal/reuse: ETA Beds

2. *Cape Byron Steiner School: Treatment of school wastewater (mainly blackwater and urinals) rich in nitrogen*

The two HSSFW beds (in series) in 1997, 8 years after commissioning.

Summary of Key Points from Monitoring

- Intensive monitoring over three seasonal periods (Winter, Spring and Summer) in parallel to monitoring the "young" Shearwater system.
- Influent rich in TN (100 – 250 mg/L) due to high proportion of urine, blackwater and composting toilet leachate.
- Removal rates for BOD and TN in school wastewater generally lower than for typical domestic sewage, due to higher proportion of TN in the influent.
- Reed beds achieved 30 – 50% removal of TN at HRT of 7 – 9 days.
- Showed signs of declining phosphorus removal after 8 years of operation (35 – 42% removal, but with occasional releases of bound P)
- One of the 1st HSSFW systems built in Australia. Design development has progressed and improved over time.

Date:	Constructed 1989
Location:	Byron Bay (Ewingsdale), NSW, Australia
Role in project:	Monitoring of system 8 years after commissioning through Southern Cross University (refer to attached paper: Headley and Davison, 1999)
Wastewater type:	School wastewater (compost toilet leachate, flush toilet blackwater, urinals, canteen kitchen)
Capacity	250 students; average HRT = 9 days (including weekend resting)
Technology used:	Treatment: Septic Tanks → Horizontal Subsurface Flow Wetlands → Maturation Pond Disposal/reuse: Irrigation of landscaped areas around the school

WETLAND + ECOLOGICAL TREATMENT SYSTEMS

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3. Treatment of nitrate-rich runoff from Bau Farm Nursery

Date:	Constructed: 2000 - 2001
Location:	Lindendale, NSW, Australia
Role in project:	Design, Construct, Plant, Commission
Wastewater type:	Horticultural runoff (nitrate and phosphate removal)
Capacity	125 m^3/day
Technology used:	Treatment: Horizontal Subsurface Flow Wetlands for nitrate and phosphorus removal Disposal/reuse: recycled for irrigation water within the nursery

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4. Decentralised Wastewater Management System for Jubullum Aboriginal Community

Date:	Designed and constructed: 2006 - 2007
Location:	Jubullum, New South Wales, Australia
Role in project:	Design, Construction, Commissioning of upgrade to failing pond system
Wastewater type:	Domestic wastewater from Indigenous community
Capacity	400 EP; 35 kL/d
Technology used:	Treatment: On-site Septic Tanks, Facultative Pond, Surface Flow Wetland (new), Horizontal Subsurface Flow Wetland (new), all without electricity. Disposal: Subsurface irrigation (LPED) of pasture and citrus trees (via gravity)
Comments:	A Surface Flow Wetland was integrated into the front end of the HSSFW in order to reduce the algal solids and BOD in the pond effluent to minimize the risk of clogging the gravel of the HSSFW.

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5. Wastewater from a Shopping Centre- treatment using recirculating VFW – HSSFW combination

Photo taken in 2017, 12 years after commissioning; still in operation.

Project name:	Modanville General Store shopping complex onsite system
Date:	2005
Location:	Modanville, NSW Australia
Client / partner:	Store Owner
Role in project:	Design, Council approvals and planting
Wastewater type:	Mixed wastewater (domestic, takeaway food shop, hair dressing salon)
Capacity:	1105 L/d
Technology used:	Treatment – Septic Tank → Vertical Flow Wetland → Horizontal Subsurface Flow Wetland with recirculation back to septic tank Disposal – Evapotranspiration/Absorption Beds

6. Wastewater Management System for Sundrop Farms (Vertical Flow Wetland)

Date:	2015 - 2016
Location:	Port Augusta, South Australia
Role in project:	Design, Construct, Commissioning
Wastewater type:	Mixed (sewage, hydroponic irrigation water and industrial wastewater)
Capacity	22 m^3/d
Technology used:	Treatment: Anaerobic Baffled Reactors followed by Vertical Flow Wetland Disposal: Evapotranspiration/Absorption Beds

7. Al Fuhais Decentralised Wastewater Demonstration Plant, Jordan

Date:	2008 - 2011
Location:	Al Fuhais, Jordan
Role in project:	Design, construction supervision, commissioning, monitoring and training for eco-technology systems at the demonstration plant
Wastewater type:	Municipal sewage
Capacity	Several demonstration scale systems, each with a capacity of 1 m^3/d
Technology used:	1) Septic Tank followed by 2-stage Vertical Flow Wetland 2) Septic Tank with Recirculating Vertical Flow Wetland

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8. *Farha Oilfield Sewage Management System (2-stage Vertical Flow System)*

Date:	2014 – 1015
Location:	Farha Oilfield, Oman
Role in project:	Design, construct, plant, commission, operate and monitor
Wastewater type:	Decentralised sewage from workers camps
Capacity	120 m^3/day
Technology used:	*Treatment:* 2 – stage Vertical Flow Wetland (raw sewage direct on 1st stage) *Disposal/reuse:* gravity loaded subsurface irrigation (LPED) field, pulse loaded using dosing siphons.
Comments:	This facility provides secondary level treatment without electricity connection to the site and eliminates sludge production by loading the raw sewage directly onto the 1st Stage VFW with integrated solids dewatering and mineralization process.

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9. Votua Village (Fiji) Decentralised Hybrid (VFW → HSSFW) System for TN removal


1st-Stage Vertical Flow Wetland under construction


2nd -Stage: three Horizontal Subsurface Flow Wetlands in parallel.

Date:	2006 – 2009
Location:	Votua Village, Fiji
Role in project:	Designed decentralized wetland treatment system for blackwater with goal of removing Total Nitrogen. Developed and installed on-site greywater management systems
Wastewater type:	Domestic wastewater
Capacity	300 EP
Technology used:	Blackwater: on-site septic tanks, STEP sewer, Vertical Flow Wetland, Horizontal Subsurface Flow Wetlands, Surface Flow wetland gardens Greywater: Coconut husk and coral rock infiltration filters

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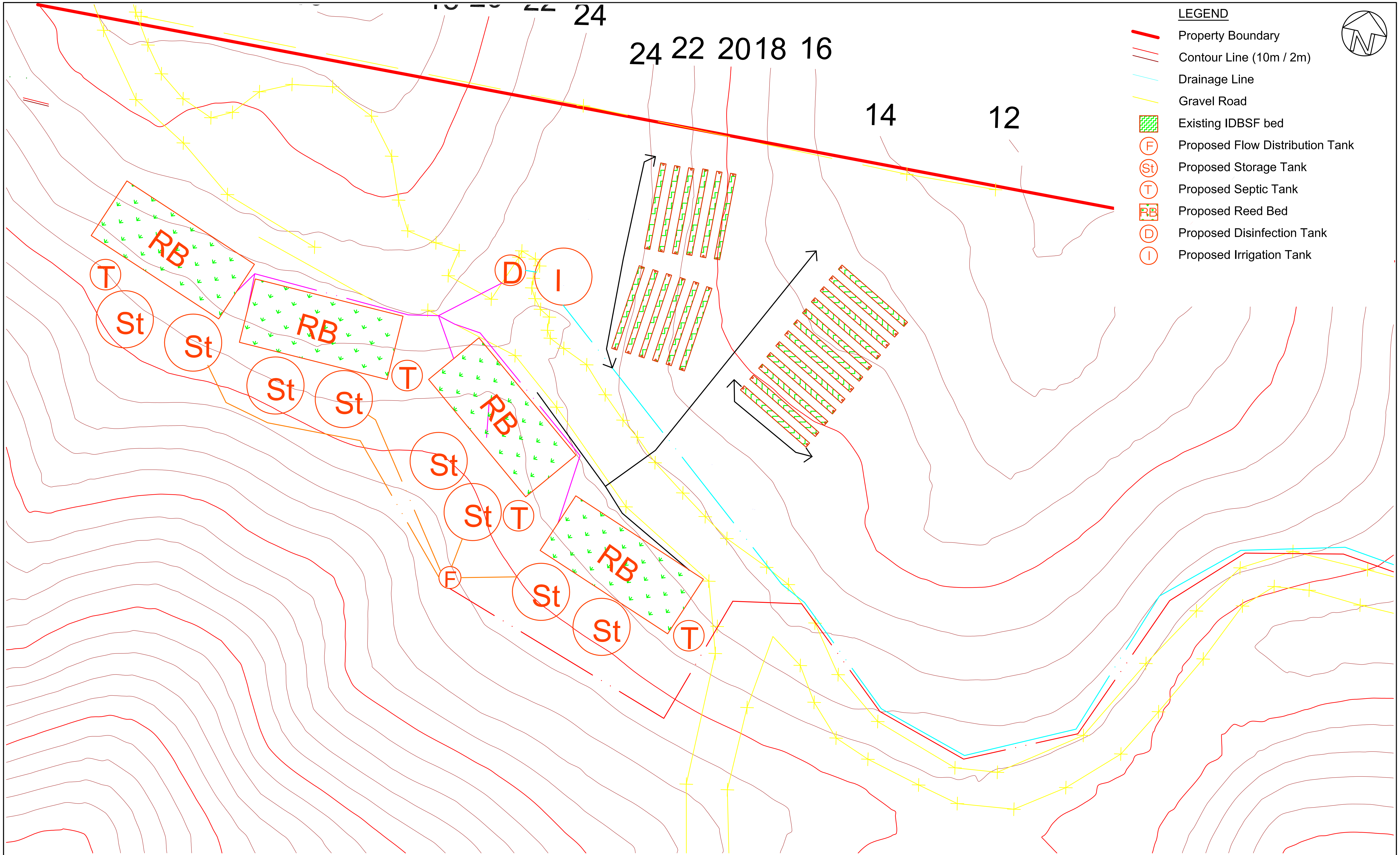
10. Langenreichenbach Ecotechnology Research Facility (Germany)

Date:	2008 - 2018
Location:	Langenreichenbach, Germany
Role in project:	Design and construct research facility, plan and coordinate research activities while head of Ecotechnology Team at the Helmholtz Centre for Environmental Research in Germany. Continuing to publish scientific papers from the research
Wastewater type:	Decentralised Domestic Wastewater
Capacity	15 x pilot plants
Technology used:	Vertical Flow Wetlands, Horizontal Subsurface Flow Wetlands, Aerated Subsurface Flow Wetlands, Reciprocating Fill and Drain beds
Comments:	We established this state-of-the-art research platform in 2008 for comparing and investigating the treatment processes in a full range of Subsurface Flow Eco-technologies of different design used for decentralized treatment of domestic wastewater. It continues to provide a wealth of knowledge and database for enhancing our understanding of these systems, as evidenced by the scientific publications produced.



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Horizontal Scale (metres) 1:800

Whitehead & Associates
Environmental Consultants

Note: AERIAL AND BOUNDARIES PHOTOGRAPHS ARE INDICATIVE ONLY.

Client: BYRON VENUE MANAGEMENT P/L

Project: WWMP FOR NORTH BYRON PARKLANDS

Title: RECOMMENDED NBP MASTER TREATMENT SYSTEM

Source: SITE LAYOUT OCTOBER 2016

Drawn:	Reviewed:	Approved:	Date:	Scale: 1:600 Approx @ A3	
HM	SD	SD	2/10/18	Job No: 1912	Sheet: 1 of 1
All units in m unless otherwise specified				Drawing No: Figure 9	Revision No: 4