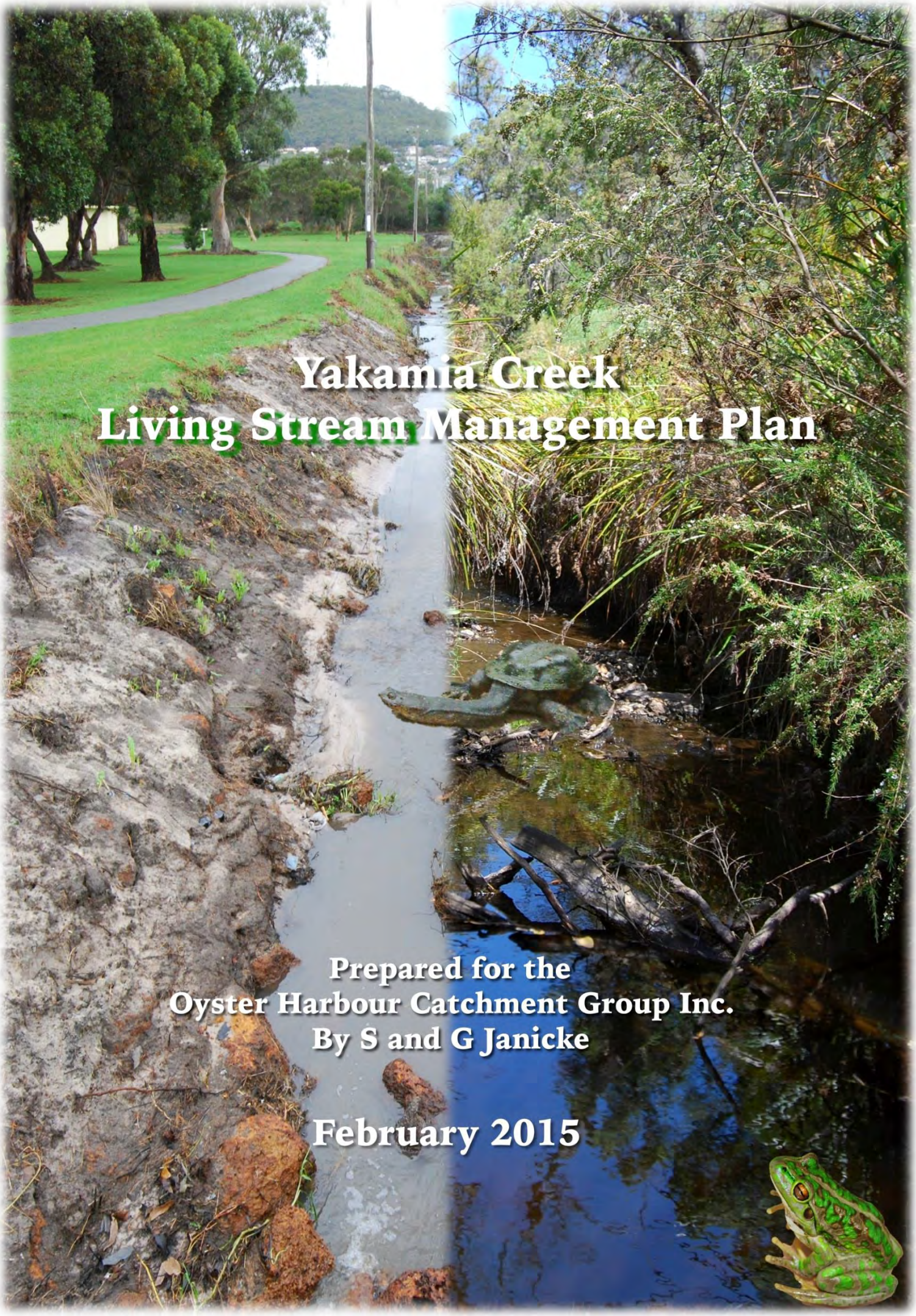


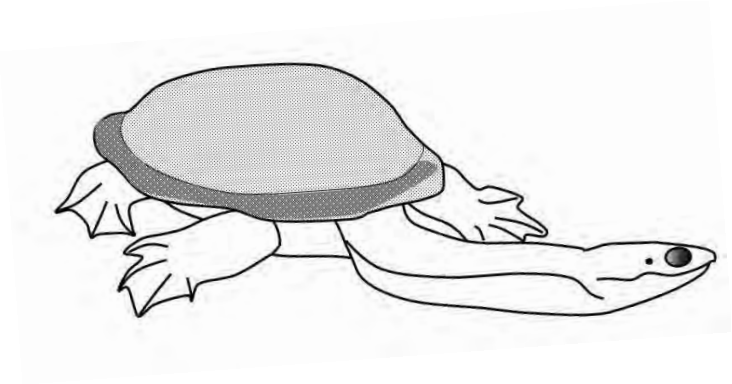
Yakamia Creek
Living Stream Management Plan

Prepared for the
Oyster Harbour Catchment Group Inc.
By S and G Janicke

February 2015

The origin of the name Yakamia Creek

The WA Department of Education Aboriginal Education website notes that; “Many local Aboriginal place names have the ending "*in*" (to the north) or "*up*" (to the south). These suffixes belong to different dialects of the Noongar language, and both mean "place of". The location of many important sites near natural sources of water has led to the common but incorrect belief that these suffixes mean the presence of water”.

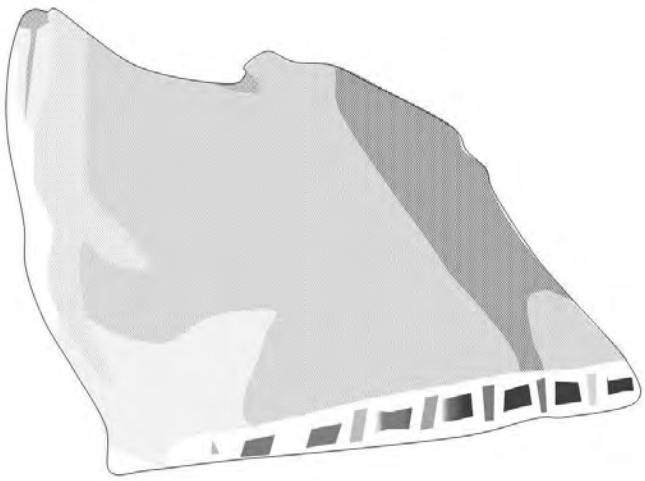


Local Albany historian Bob Howard (*A Noongar History of Albany*) noted that the lower Yakamia Creek locality was formerly known as *Yakinup* from *Yakin* – the long-necked tortoise. The locality can therefore be understood to mean, *the place of the long-necked tortoise*.

The name Yakamia is considered to be a combination of two words, *yaka* and *mia*.

The Aboriginal name for temporary shelters constructed at campsites is *mia* or *myah*. This suggests a subtle variation in meaning for *Yakamia*, perhaps originally referring to a campsite. Interestingly, the area around Duck Lake (now renamed *Weelara*) near the junction of Albany Highway and Hanrahan Road was a traditional campsite and it also lies on the Yakamia Creek watershed at the end of the granite ridge which descends from Mount Melville.

To complicate matters, the word *Yacka* refers to a wild dog. The iconic Dog Rock, which lies on the southern watershed of Yakamia Creek near the top of York Street, was known as *yaccan toort*.



A Wikipedia entry suggests that Yakamia is thought to mean ‘sister to a small creek’ in the Noongar language. The origin of this interpretation is unclear. Nevertheless it can be noted that the upper Yakamia Creek branches into several minor drainage lines. These small tributaries might easily be described as sisters, one of which is said to have been spring fed and of course, fresh water is a necessary feature of a favored campsite.

YAKAMIA CREEK
LIVING STREAM MANAGEMENT PLAN

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Final	YAKAMIA CK LSMP.docx	13/03/2015	OHCG		Final

Contents

Overview

This report provides a systematic overview of the nature of the main trunk of Yakamia Creek between the watershed at Anson Road and its confluence with Oyster Harbour. The overview also includes four tributaries, two in the Centennial Park precinct and two entering the creek from the western side of the catchment below North Road. Seven floodway zones were identified on the basis of their position in the catchment landscape. Within these zones, 108 discrete sections of the floodway were delineated, each with distinctive attributes. The sections cover 15.5 Kilometres of stream channel, 9.4 Kilometres of the main trunk and 6.1 Kilometres of tributary. The general management issues for each of the sections was assessed and rated in terms of constraints on environmental rehabilitation opportunities. Five key types of constraint were identified under the following headings; area of riparian space available, stormwater conveyance, land tenure (use) issues, public amenity and maintenance issues. A short list of sections suitable for Living Stream projects in the near future was distilled from the assessment in Table 6: Tier 1 Summary of opportunities, objectives and design considerations.

The section 'Recommendations to Oyster Harbour Catchment Group' focuses more on the contribution the group can make to promoting a holistic approaching to the management of Yakamia Creek rather than offering prescriptive engineering solutions to specific technical problems, for example the poor water quality or how to deal with flooding in the lower catchment. The greatest hindrances to integrating an environmental plan with other management plans for the creek, are social in nature.

Management recommendations for landholders downstream of North Road are given as 'Best and better foreshore management practices for the lower Yakamia Creek' as appropriate to overall character of that part of the floodway environment. The authors consider this is an interim measure pending the acceptance by all stakeholders of the long term goal of creating a continuous riparian corridor along the lower catchment and associated tributaries.

The Oyster Harbour Catchment Group Inc. (OHCG) have more than twenty years collective on-ground experience in managing river and creek systems and are well positioned to contribute practically to projects, in collaboration with other stakeholders. An important strength of the OHCG is an understanding of and commitment to successful environmental outcomes for projects in the long term. Maintenance of Living Stream sites is crucial to achieving those outcomes and a failure in this area can undo a lot of good work. Recommendations to the OHCG for progressing Living Stream project opportunities and levels of involvement are provided in 'Recommendations to OHCG for Tier 1 sites' and 'Summary of General recommendations to OHCG for Tier 2 sections downstream of North Road.

Two important supplementary documents are provided. Supplement 1 presents seven urban Living Stream projects from other regions. These have been chosen because they have issues in common with Yakamia Creek. These are not 'fill' for the report, but each case study provides useful insight into the realities of Living Stream development in urban areas and the lessons learnt. This is after all a relatively new field of urban development and this report emphasizes that success depends on a significant change in community expectations regarding how the stream should be managed into the future. Supplement 2 is a geo-referenced photographic record of the target creek sections, here called a Photo-audit. This provides a visual overview of the status of the system in 2014 and highlights various management issues.

The Living Stream Management Plan emphasizes that stakeholder consultation is more than a 'hoop' to jump through in order to achieve an environmental goal. It is a critical ongoing component for sustainable management of the creek system.

Introduction

The aims of this management plan are to:

- Provide recommendations on appropriate management of Yakamia Creek by private landholders, the City of Albany and State Government agencies.
- Identify, and propose solutions for key problem areas and issues.
- Inform environmental rehabilitation priorities for natural resource management stakeholders, the City of Albany and State Government agencies.
- Identify the next 2 to 5 rehabilitation sites for Yakamia Creek Living Stream Projects.

A Living Stream Management Plan presents opportunities for rehabilitation of fragmented urban waterways, opportunities that are both desirable and feasible with respect to their ecological health. It also considers the various social benefits.

It has been estimated[1] that by 2050 approximately 80% of the world population will be living in cities. The passage of water through these areas, its quality and function as an essential resource, requires a sophisticated management approach.

The aim of a holistic waterways management plan is to return continuity of riparian form and function to urbanised catchment streams. Without a significant consensus by the urban population this this can only be achieved in part. The defining characteristic of many urban streams is the fragmentation of their floodway form. There are abrupt changes at cadastral boundaries and a lack of continuity of riparian structure from the watershed to the lowest point in the catchment and from one reach to the next. The fragmentation of urban streams is not only created by division imposed by land tenure, but is compounded by differing expectations regarding the role that the waterways play in the environment. Developers have traditionally given little thought to the matter of riparian continuity. Nevertheless, urban streams are continuous in a hydrological sense, provided flows are not totally impounded. Neither is a stream simply defined by the main trunk, but it includes the branching network of tributaries and many minor swales and gullies that capture rainfall and steer it downhill. A water sensitive city manages its waterways and water resources in a holistic, rather than a piecemeal fashion. The City of Albany is well placed to becoming a water sensitive city.

The City of Albany's vision[2] for the next ten years is to be clean, green and sustainable. Within the objective to protect and enhance our natural environment, the City has endorsed actions that protect and enhance the health of our waterways including providing habitat for local flora and fauna.

The expanding demands of urban development have tended to an acceptance of environmental projects, provided they fit into the vacant spaces that are of less interest to developers and provided they cause no disruption to existing drainage infrastructure. That perspective is changing. For example the CRC for Water Sensitive Cities based in Melbourne, has chosen the City of Geraldton in WA, to demonstrate how regional centres can become models of water sensitive urban design. It is suggested that the City of Albany is well suited to demonstrate a progressive approach to urban water management, one that goes beyond the disposal of inconvenient stormwater.

Notwithstanding the above aims of this management plan, it is not a flood management plan nor is it a stream restoration plan in the accepted sense. Typically, a stream restoration plan (also called a river action plan) is developed for relatively intact streams which have retained their essential

[1] Uniview, 2014, Vol 33/2

[2] City of Albany (2014) '*Community Strategic Plan Albany 2023: Our Vision*'

natural features, but are experiencing degradation due to human activity. A restoration plan describes the pre-disturbance characteristics of a waterway and suggests how it might be defended against a range of pressures in order to limit and if possible reverse degradation. In a river action plan works that promotes protection and recovery are recommended. This usually involves protective measures such as fencing to exclude stock, re-vegetation with local riparian plant species in areas where they are disappearing, the provision of stable crossings and other infrastructure. A River Action Plan also provides guidelines for best management practices. In some cases restoration may involve intervention in the form of bed and bank stabilization works, but preferably using natural materials such as vegetation, loose rock and wood. This approach is referred to as *soft engineering*.

A Living Stream Management Plan (LSMP) starts with a degraded and fragmented urban waterway and considers ways to introduce ecosystem attributes that are compatible with the multiple constraints that urbanization has created. These attributes will not necessarily represent the original natural state of the waterway. For this reason, the term *retrofitting drains* has been attached to the Living Stream concept. Nevertheless, there are commonalities between restoration and Living Stream rehabilitation, particularly where there are pockets of remnant riparian vegetation. In those situations protection measures may be the main management tactic. Some sections of the lower Yakamia Creek tributaries appear to fit into this category. Two requirements for developing a Living Stream Management Plan for Yakamia Creek (LSMP) are first to understand the character of Yakamia Creek itself and secondly to identify the constraints on appropriate environmental management.

For these reasons a holistic ecosystem concept plan for Yakamia Creek, one that considers in detail both ecological and social amenity along its entire length from the watershed to Oyster Harbour, would prove useful. This report lays a foundation for such a plan and it will always be a work in progress. Short-term projects should therefore be undertaken with a long-term view in mind, a view that will span many decades.

Overarching city planning requirements

The City of Albany's Community Strategic Plan 2023[1] presents the vision "To be Western Australia's most sought-after and unique Regional City to love, work and visit." Under the theme of being clean, green and sustainable, the Strategic Plan states that "our community loves the City's natural assets, coastline and green spaces within our municipality." The vision for a sustainable city includes environmental actions to "promote habitat protection and encourage development that incorporates or re-establishes ecologically sound vegetation and waterway corridors". The Planning objective is, "to preserve the natural ecological and drainage function of water courses, drainage systems and floodplains and limit the potential for damage to buildings caused by flooding and/or inundation." This is a challenging task.

A number of investigative reports and management plans for Yakamia Creek have been prepared for the City of Albany and are relevant to this document. These documents describe the factors that will support or constrain the development of environmentally focused projects along the creek.

Some key documents are;

- Yakamia Creek Arterial Drainage Plan (2014)[2].
- Community Strategic Plan, Albany 2023

[1] City of Albany (2014) '*Community Strategic Plan Albany 2023: Our Vision'*

[2] Essential Environmental. (2014) '*Yakamia Creek Arterial Drainage Plan'*. Prepared for the City of Albany.

- Yakamia Structure Plan area – City of Albany Environmental Assessment – opportunities and constraints. (2013)[1].
- City of Albany. Flood Management Plan, Yakamia B Catchment. Prepared by Opus International Consultants (2006).
- Yakamia Creek – Albany Floodplain management Strategy (2002). Prepared by the Water and Rivers Commission.
- City of Albany 2010 *Albany Local Planning Strategy*
- City of Albany Policy (2014) Yakamia/Lange Structure Plan
- Centennial Park Sporting Precinct Master Plan

The characteristics of Yakamia Creek

Yakamia Creek is the smallest of three main catchment systems feeding water into Oyster Harbour, the other two being the Kalgan River and the King River. Another smaller catchment is Johnson Creek that enters Oyster Harbour between the mouths of the King and the Kalgan Rivers. The catchment area of Yakamia Creek is approximately 21 Km^2 (0.8% of the total Oyster Harbour catchment area) compared to the Kalgan River at 2562 Km^2 and the King at 375 Km^2.

There are several short tributaries feeding into the main trunk of Yakamia Creek. Those in the upper urban catchment are ephemeral and many sections are piped underground. Two short drainage lines descending from the Mount Clarence ridge have been included in this report. There are also two tributaries, extending from the north west side of the catchment near Mason Road (Lange) and Callistemon View / Range Road and these have their confluence with the main trunk between North and Lower King Roads. These tributaries do not have official names and it would be helpful to promote community awareness of their existence their need of some level of protection, by naming them. For the purposes of this report, the tributaries will be referred to as Lange tributary and Callistemon View tributary.

Recommendation: That names be given to the two larger tributaries, extending from Mason Road (Lange) and Callistemon View / Range Road that enter Yakamia Creek between North and Lower King Roads.

Divisions of the creek line

The historical allocation of land along the creek for urban development, has essentially divided the main trunk into two zones with different land tenure issues. The upper zone (35% of the main channel) is predominantly City land with public amenity and the middle to lower zone (65% of the main channel) is mostly private land (see Figure 1).

In addition, the two short tributaries entering the floodway downstream of North Road have remnant vegetation areas that are still in reasonable condition and these are of environmental interest with respect to conservation. These two tributaries flow through privately owned land. The Mount Clarence/ Melville drainage lines service the Centennial Park precinct. Together these four zones suggest different priorities and focus for achieving desirable environmental outcomes for Yakamia Creek. The overarching management issues for the four zones are summarised in the Table 1 below.

[1] Melanie Price (2013) '*Yakamia Structure Plan Area, City of Albany Environmental Assessment - Opportunities and Constraints*', Report No. AA2012/020 by Aurora Environmental for the City of Albany.

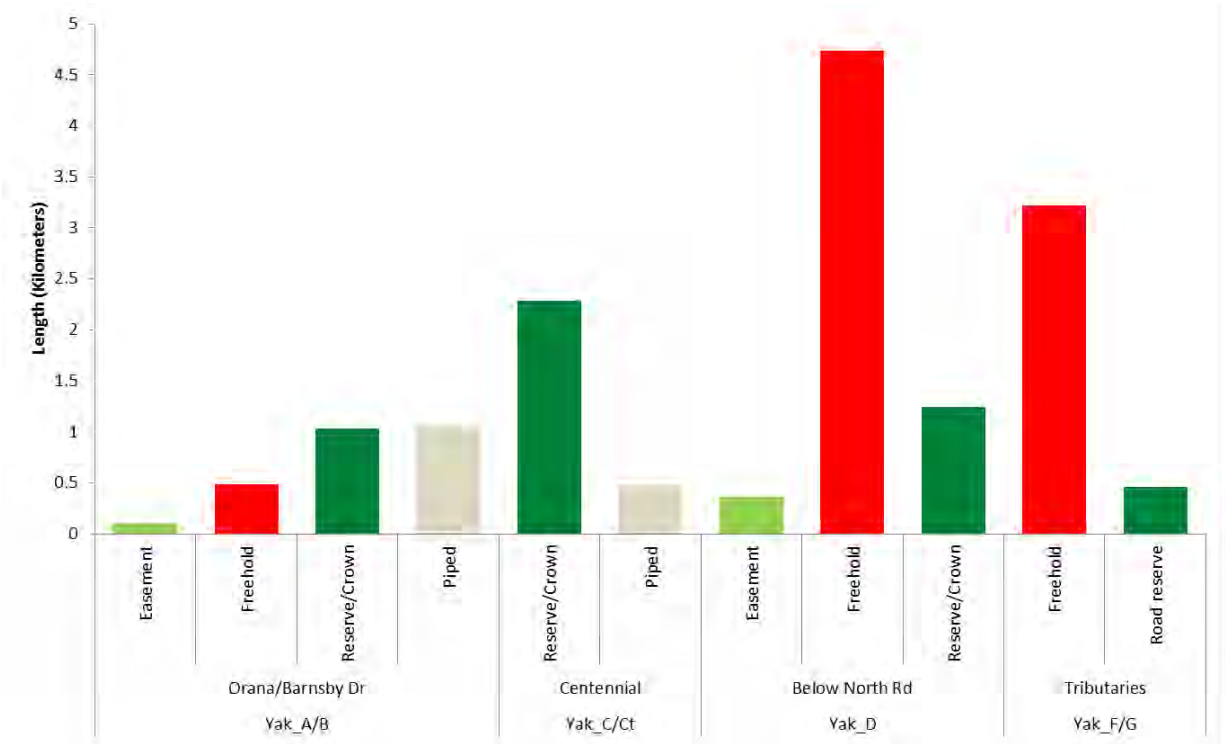

Figure 1: Tenure of Yakamia Creek and its tributaries.

Table 1: Overarching environmental management issues for the four zones of Yakamia Creek.

Zone	Strength	Weakness
Upper Yakamia	Primarily subject to City of Albany management and offering various public benefits.	Highly fragmented floodway form defined by diverse management demands and community interests.
Centennial Park recreation precinct	Predominantly public open space with opportunities to improve riparian continuity and function. The Centennial Park Sporting Precinct Development Plan	Physically fragmented drainage lines with current and expanding recreational facilities setting the precedent for area use.
North Road to Oyster Harbour.	Relatively consistent channel form and general management requirements. Technically these reaches lend themselves to significant reconstruction.	Subject to diverse landholder preferences and expectations. Private ownership.
Western tributaries (Callistemon View and Lange)	Potential for conservation of existing channel form with associated remnant scrubland and woodland in moderately good condition.	Subject to increasing pressures from high density urban development upstream and potential subdivision requirements. Severe threat from weed encroachment. Private ownership.

Channel geomorphology and hydrology

The longitudinal bed slope of the main trunk of Yakamia Creek, from the watershed to the mouth, provides a foundation for understanding the fluvial geomorphology of the floodway. Fluvial geomorphology refers to the connection between the underlying geological structure of the catchment and the way in which rainfall runoff and groundwater shapes the drainage system. Urban development modifies these ancient processes creating new pressures on the creek. The lengthways

bed slope (Figure 2) reveals potential high and low energy sections with respect to water velocity (stream power), although bed slope is not the only factor controlling flow velocity. Steeper slopes indicate reaches that have a higher risk of erosion and low slopes indicate reaches prone to sediment deposition (where flow slows down). Bed and bank stability also determine the level of risk of degradation in erosion and sedimentation prone areas. In areas with low cohesive sandy soils, vegetation plays a critical role in bed and bank stabilisation.

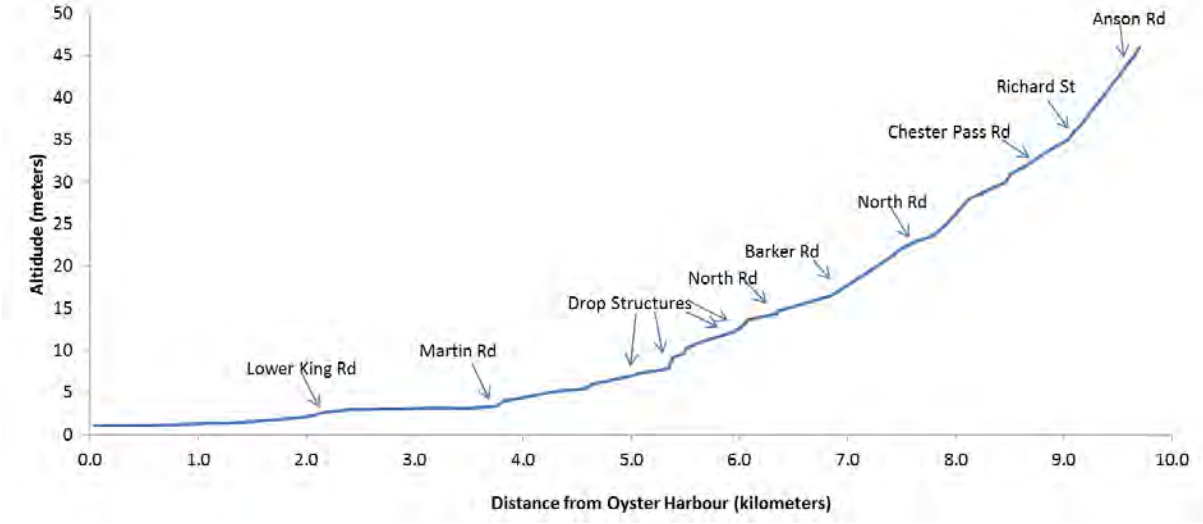

Figure 2: Longitudinal bed altitude profile of Yakamia Creek

The longitudinal bed profile matches well with the four management zones defined above. The profile, from the watershed above Anson Road to Oyster Harbour, has the relatively smooth concave-upward form of a graded stream channel. A graded stream is one for which a balance has been created over time between the amount of erosion and the transportation/ deposition of sediment. There appear to be no major geological discontinuities along the profile, although a layer of subsurface coffee rock was observed in several sections and is responsible for local irregularities in the bed slope. An example of this is the head-cut (waterfall) a short distance downstream of the North Road and Sanford Road intersection (Figure 3).

Figure 3: The waterfall and head-cut a short distance downstream of the North Road and Sanford Road intersection. The upstream progress of the headcut has been slowed by a coffee rock layer.

There are a number of artificial drop structures (Figure 11) along the lower reaches of the creek. These were installed to reduce the energy of flow when the creek line was straightened thus increasing the local bed slope and discharge velocity. A drop structure controls the water surface slope and is typically constructed on minor streams to move water to a lower elevation with the controlled dissipation of flow energy as it passes over. By removing energy from the flow, and hence reducing the water velocity, a drop structure may reduce the overall erosion risk further downstream. Nevertheless, if poorly designed, the section of channel immediately downstream may be at greater risk of erosion, typically, deepening and widening the channel. Unlike dams, drop structures are not built for water impoundment, diversion or raising the water level. The drop structure can aid oxygenation of the water, but can also hinder ecological processes, for example the movement of fish upstream for spawning.

The drop structures along the lower Yakamia Creek were required to offset the removal of meanders when the channel was straightened. Meanders moderate the slope of the channel and hence the erosive power of the flow. The observed bank erosion along the channel is explained in part by the tendency of the stream discharge to recreate natural meander form. For this reason projects that favour reinstatement of sinuosity in the straightened channel are preferred for enhanced environmental and hydrological function. Sinuosity (channel curvature) also increases hydraulic and terrestrial habitat diversity.

Channel sinuosity is a desirable feature of Living Streams.

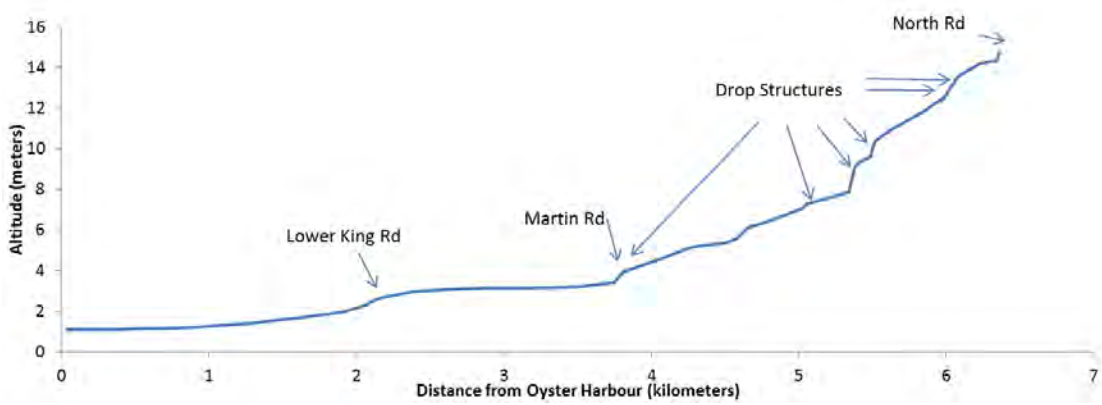

Figure 4: shows more detail of the bed slope downstream of North Road. Note how the slope quickly levels out.

The average channel bed gradient from the watershed to Oyster Habour is moderate, at approximately 0.005 (a 5 metre fall over 1000 metres). However, the upper part of the channel has a higher mean gradient of approximately 0.009 (9 metres per 1000 metres) compared to a very low gradient of approximately 0.0015 (1.5 metre fall over 1000 metres) in the lowest reaches of the creek (Figure 4). The very low slope in this zone is consistent with it being a natural sediment deposition area with a wide floodplain developed over thousands of years. This area would likely have been estuarine in character for some periods in the past. Yakamia Creek is still influenced by tides for approximately 2 Kilometres upstream of its outfall at Oyster Harbour. This would likewise tend to hinder stream discharge and promote sediment deposition.

A cursory examination of the channel through the foreshore reserve upstream of its entrance into Oyster Harbour provided some evidence of the amount of sediment deposition in the vicinity of the mouth of the creek. Figure 5 below shows the relatively flat bed profile of the 400 metre long reach upstream of the mouth. There is some evidence of a long sediment plume between 50 and 200

metres and an associated scour hole at the narrow outfall. There is also a slightly deeper pool between 150 and 250 metres upstream.

The foreshore area out from the mouth appears to have features characteristic of long-term deposition processes. No studies of sediment discharge into Oyster Harbour were located, but sediment cores may provide a clearer picture of the impacts of urban development over the past two hundred years. This investigation may provide a useful project for a university Honours student.

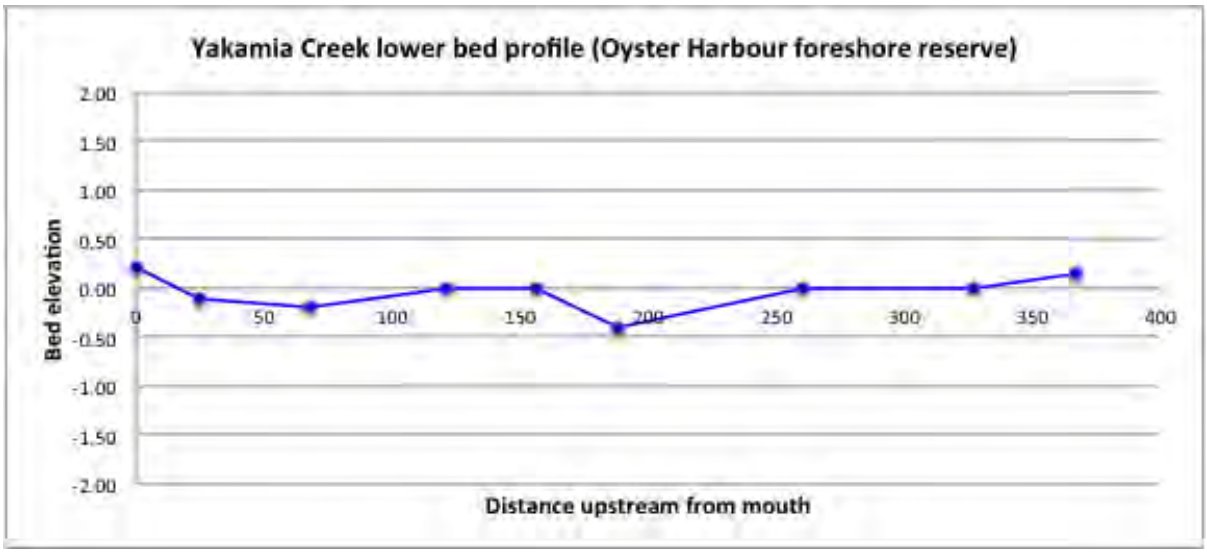

Figure 5: The creek bed profile of the first 400 metre reach going upstream from the mouth of Yakamia Creek

In addition to stormwater runoff, groundwater discharge into Yakamia Creek is a significant hydrological feature and accounts for general stream flow when it is not raining. Seepages can be seen along the banks in all four zones but appear more significant between North Road and Lower King Road. A number of properties along the lower reaches have various lateral drains to direct groundwater seepage into the creek line. Much of the catchment area is underlain by acid sulphate soils (ASS) that if exposed to the atmosphere generates sulfuric acid that degrades water quality and impacts vegetation as well as deteriorating built infrastructure. The presence of acid sulphate soils at shallow depths imposes a natural constraint on both urban development and Living Stream project designs. Interestingly there is evidence of acidification of top soil in some areas and these bare areas have similar features to salt scalds. There has been some pressure to dig the channel deeper to improve drainage efficiency however, the high risks associated with exposing acid sulphate soils makes this option unwise.

Centennial Park is underlain by Spongeolite, a friable sedimentary rock partly composed of clay silts and the breakdown products of marine sponges from a time when the ocean covered the land. The impervious granite hills (plutons), Mt Clarence, Mt Melville and uplands of Spencer Park and Yakamia/ Lange feed groundwater flow to the creek. The groundwater system is therefore an important factor affecting water quality, Riparian management should include areas further from the dominant channel where groundwater seepage occurs and this is as important as managing the channel itself.

The condition of Yakamia Creek downstream of North Road/ Sanford Road.

The condition of the riparian zone of Yakamia Creek along the lower reaches can be aptly described as a weed infested ditch. Interestingly, in places where there is a diversity of competing weeds, including larger woody species, this has promoted the creation of channel features that have a more natural form. These areas now form a complex, though non-natural ecosystem. Land use and the type of weed management used on a property are two factors that have a significant influence on riparian character and development.

Flora

The authors have not been able to find any clear photographic records or detailed descriptions of the early-settlement vegetation in the Yakamia Creek area. Sandiford and Barrett (2010)[1] described the *Taxandria juniperina* (Swamp Cedar) Closed Forest vegetation unit as the most commonly found vegetation around swamps, freshwater lakes and along drainage lines that once formed extensive groves on the drained flats around Albany. Mature stands of Swamp Cedar can be seen along sections Yak_C1, Yak_D2.2 and Yak_D5.7 (See maps 1, 5 and 8 respectively). Mature stands generally have fewer understory shrubs and were more open. However they are easily killed by fire and regenerate from seed forming very dense thickets. *Callystachys lanceolata* (Wonnich) occurs with Swamp Cedar and where local soaks or seepages occur on sandy to peaty soil. It is most likely that Swamp Cedar was the dominant vegetation, either as tall closed forest or dense thickets around the flats of North Road and the flats adjacent to Ulster Road. Other vegetation units along the Yakamia floodplain are *Homalospermum firmum/Callistemon glaucus* (Albany bottlebrush) (See Figure 6) Swamp Thicket, *Astartea scoparia (*Tea tree Swamp) Thicket, *Evandra aristata* Sedgeland *Melaleuca cuticularis/M. preissiana* (Paperbark) Open Woodland and *Baumea articulata* Closed Sedgeland.

Figure 6: *Homalospermum firmum* and *Callistemon glaucus* (Albany bottlebrush)

Sandiford and Barrett (2010) noted that these units were susceptible to weed invasion with Sydney Golden Wattle (*Acacia longifolia*) and Taylorina (*Psoralea pinnata*) commonly observed within them. There are many other weeds throughout the remnant vegetation of the floodplain including Pampas Grass (*Cortaderia selloana*) and Gorse (*Ulex europaeus*). Melanie Price (2013)[2] of Aurora

[1] Sandiford, E.M. and Barrett, S. (2010). *Albany Regional Vegetation Survey, Extent Type and Status*, A project for the Department of Environment and Conservation. Unpublished report. Department of Environment and Conservation, Western Australia.

[2] Melanie Price (2013) *Yakamia Structure Plan Area, City of Albany Environmental Assessment - Opportunities and Constraints*, Report No. AA2012/020 by Aurora Environmental for the City of Albany

Environmental commented that much of the vegetation associated with Yakamia Creek does not constitute native vegetation due to almost complete invasion by weeds. Despite the proliferation of weeds, there are some moderately healthy vegetation remnants along parts of the short tributaries entering the main channel near Mason Road (Lange tributary) and Range Road (Callistemon View tributary).

Upslope, *Taxandria parviceps* (Tea Tree) transitional Shrubland occurs on grey sand or in pockets of poorly drained sand over laterite. This gives way to Jarrah/Marri/Sheoak Laterite Forest, Jarrah/Sheoak/Albany Blackbutt Sandy Woodland and Banksia coccinea Shrubland/ Albany Blackbutt /Sheoak Open Woodland. Melanie Price (2013) presents a detailed description and maps of the existing remnant vegetation communities within the Yakamia Lange localities including the priority flora and priority ecological communities present.

Fauna

Yakamia Creek is named as the home of the long-necked tortoise (*Chelodina oblonga*). It has not been recorded in any studies; however one was accidently excavated in 2013 during the construction phase of the Yakamia Creek Living Stream adjacent to Barnesby Drive (Mark Waud per comm.) A number of residents along Ulster Road have also commented on seeing the long-necked tortoise.

Melanie Price (2013) has listed vertebrate species[1] recorded from various recent and historical surveys in the region and outlined the number of species recorded and their status by group which is reproduced below (Figure 7). Her recommendation regarding fauna was: "Retention of vegetation suitable for Threatened Black Cockatoos, Western Ring-tail Possums and Priority Quenda are most likely to benefit other significant species which may occur in the area. These fauna habitat types comprise a combination of Jarrah/Sheoak/Albany Blackbutt Sandy Woodland and Wetland Mosaic vegetation. It will be most beneficial to retain elements of these vegetation types which enhance connectivity and coincide with other significant features (e.g. wetlands and watercourses)."

[1] Appendix H in Melanie Price (2013) *Yakamia Structure Plan Area, City of Albany Environmental Assessment - Opportunities and Constraints*, Report No. AA2012/020 by Aurora Environmental for the City of Albany

FAUNA SPECIES BY GROUP

GROUP	NUMBER OF SPECIES	COMMENT
Frogs	Five of a possible 14 species found in the region.	No Threatened or Priority species recorded
Reptiles	Eighteen species of reptiles including 12 skinks, three elapids, one gecko, one pygopod and one varanid. An additional 16 species of reptiles are known to occur in the region but were not recorded in YSPA.	No Threatened or Priority species recorded
Birds	Fifty-nine bird species were recorded in YSPA. A total of 150 bird species are likely to be found in the Albany region. However, many are associated with marine habitats and are not likely to utilise or rely on the YSPA.	Carnaby's Black Cockatoo Baudin's Cockatoo Red-tailed Black Cockatoo
Mammals	Eleven native species of mammals were recorded in the YSPA including three bat species. Three introduced species were recorded (cat, fox and rabbit).	Western Ring-tail Possum Southern Brown Bandicoot

Figure 7: Numbers of vertebrate fauna species recorded from various recent and historical surveys in the Albany region (Source: Melanie Price (2013)

Aquatic fauna

There have been no systematic aquatic fauna studies done in the Yakamia catchment. Studies[1] in the adjacent and similarly fresh Marbellup Creek and King River show a high diversity of aquatic invertebrates and fish exists in the region and would likely have existed in Yakamia Creek. Fish and crayfish species present in the region and potentially present in Yakamia Creek are:

- Mud Minnow (*Galaxiella munda*),
- Nightfish (*Bostockia porosa*),
- Pouched Lamprey (*Geotria australis*)
- Western Minnow (*Galaxias occidentalis*),
- Western Pygmy Perch (*Nannoperca / Edelia vittata*),
- Gilgie (*Cherax quinquecarinatus*)

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1 Barbara A Stewart (2011) An assessment of the impacts of timber plantations on water quality and biodiversity values of Marbellup Brook, Western Australia. Environmental Monitoring and Assessment (2011) 173:941–953

Cook, B. A., Janicke, G. & Maughan, J. 2008. Ecological values of waterways in the South Coast Region, Western Australia. Report No CENRM079, Centre of Excellence in Natural Resource Management, University of Western Australia. Report prepared for the Department of Water.

Janicke, G., Cook, B. A. & Maughan, J. 2008. Ecological values of the King River in relation to waterways in the South Coast Region, Western Australia. Report No CENRM098, Centre of Excellence in Natural Resource Management, University of Western Australia. Report prepared for the Department of Water.

Morgan, D. L., H. S. Gill and I. C. Potter (1998). "Distribution, identification and biology of freshwater fishes in southern-western Australia." Records of the Western Australian Museum (Supplement No. 56).

- Gilgie sp. (*Cherax crassimanus*)
- Koonac (*Cherax preisii*),
- Smooth Marron (*Cherax cainii*),

An opportunistic water sampling exercise for fish and macroinvertebrates was undertaken in the King River and Yakamia Creek by the authors, in collaboration with Department of Fisheries Community Education Officer Tahryn Thompson and University of Western Australia fish ecologist Dr Paul Close (CENRM) on 29th November 2014. In the King River three species of native fish, (Nightfish, Western Minnow and the Western Pygmy Perch), and two species of freshwater crayfish Smooth Marron and Koonac) were collected. The introduced Gambusia (*Gambusia holbrooki*), was also collected (See Figure 8.)

The site chosen for sampling in Yakamia Creek was Section Yak_D2.4 (see map 5) which is between two drop structures. The only fish collected were the introduced Gambusia and the only freshwater crayfish were the introduced Yabby (*Cherax destructor*) (See Figure 9). There were also fewer aquatic macroinvertebrates present in the sample collected from Yakamia Creek. The drop structures are significant barriers to native fish movement. Sampling in the two tributaries, (Sections F and G on maps 6, 9 and 10) and lower down in Yakamia Creek would help to determine if any native fish still live in the Creek.

These observations suggest:

- Living Stream project success may be determined in part by monitoring fauna and flora diversity and numbers.
- The re-introduction of native aquatic species into re-engineered habitats is a possibility.
- Monitoring bird numbers and diversity is a good indicator of increased invertebrate diversity in rehabilitated sections (See Bannister Creek case study.)

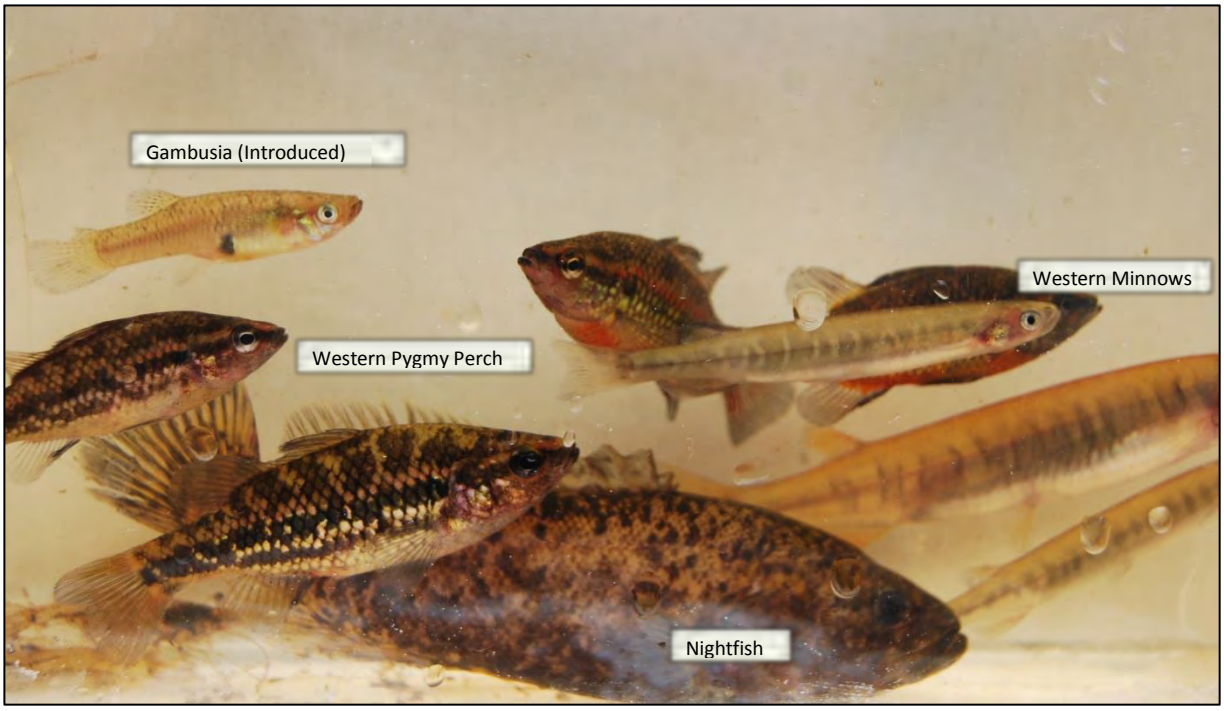

Figure 8: Fish netted from the King River that would once have lived in Yakamia Creek, except for the introduced Gambusia. (Photo by S. Janicke)

Figure 9: The Yabby (*Cherax destructor*) has been introduced from the eastern states competes with our local endemic freshwater crayfish.

Aboriginal Heritage

An Aboriginal heritage survey and consultation was undertaken for the Yakamia/Lange Structure Plan[1] area and this saw Yakamia Creek registered with the Department of Indigenous Affairs (DIA) as a site under Section 5(b) of the 'Aboriginal Heritage Act 1972' (Figure 10). The ten members of the Aboriginal Heritage Reference Group Aboriginal Corporation (AHRGAC) requested that provisions be made so that Yakamia Creek has a buffer zone (30m) where no urban development takes place and that the creek line be rehabilitated with local native plant species.

The continuous riparian buffer as recommended, is compatible with the preferred Living Stream ideal of riparian continuity along a stream and the 30 metre buffer is generally applicable upstream of North Road. However, a 30 metre buffer should be considered a minimum requirement downstream of North Road and in those reaches the riparian corridor width should be extended to amply accommodate the geo-morphological attributes of the broader floodway as well as the main channel.

Any Living Stream rehabilitation planning for sections of Yakamia Creek registered with the Department of Indigenous Affairs should include Noongar consultation in the design phase. Any rehabilitation activities that - *dig any hole or otherwise disturb the surface of the ground, or remove or disturb any stone, soil, sand, rock or gravel, or any other natural object* - will require consent according to Regulation 10 of the Aboriginal Heritage Regulations 1974. Further information on notification requirements can be found on the State Governments Department of Aboriginal Affairs website.[2]

[1] City of Albany Policy (2014) Yakamia/Lange Structure Plan

[2] http://www.daa.wa.gov.au/en/Heritage-and-Culture/Resources/Policies-and-procedures/Regulation-10/

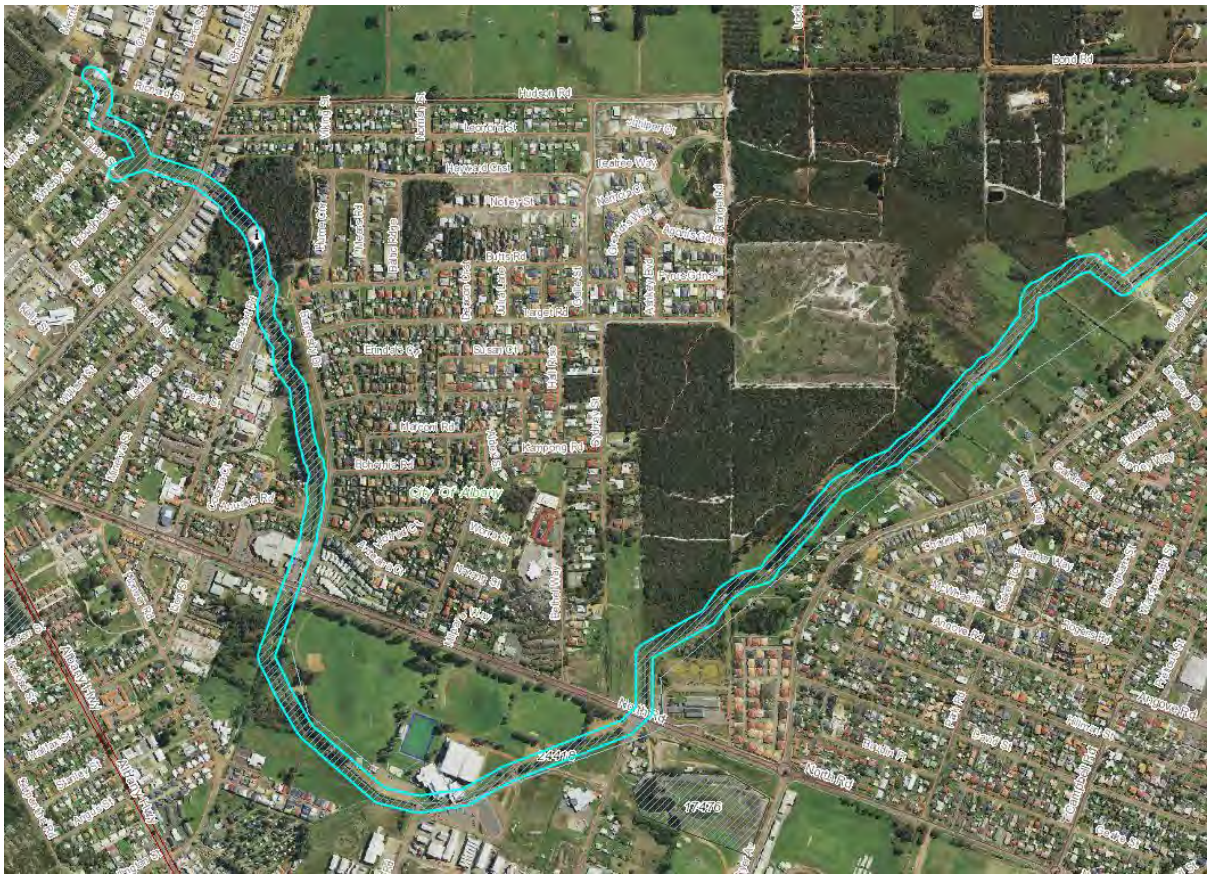

Figure 10: Aboriginal Heritage Sites – showing the 30m buffer zone requested by AHRGAC. (Source Department of Aboriginal Affairs Aboriginal Heritage Inquiry System (http://maps.dia.wa.gov.au/AHIS2/) accessed 16th February 2015. [1]

A Brief Management History of Yakamia Creek

Yakamia Creek is an ecosystem that warrants more than the title – drain. A common misconception regarding the definition of a creek is that it only consists of the most obvious low flow channel. The extent of the floodplain contradicts this view. Yakamia Creek was and is, a composite of flow paths as it meanders toward the inlet and is connected to the groundwater recharge (source areas) and discharge (outflow) areas along the floodway. The riparian zone is the interface between the upland valley sides and the channel and it is influenced by groundwater flow, as well as the surface flows. Although most parts of the creek are now highly channelized to facilitate faster drainage of the riparian flats, the low flow dominant channel is only one part of the waterway system.

The dominant channel of Yakamia Creek would likely have slowly migrated back and forth across the floodplain areas over the centuries as a result of the meandering habit of natural streams. This process would have been strongly influenced by changing vegetation distribution, density and type. The buildup of woody material and the redistribution of sediment would also have promoted changing flow paths. The occasional severe storm event, drought or bushfire would also have affected the ongoing processes of erosion and sedimentation and hence channel location. Secondary

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[1] Topographic maps and data copyright © Commonwealth of Australia, Geoscience Australia (2015). Aerial Photos, Cadastre, Local Government Authority, Native Title boundary, Roads data copyright © Western Australian Land Information Authority trading as Landgate (2015)

channels and backwaters may have developed within the broader flood prone areas reflecting various flood events and changing vegetation conditions.

In 1959 the Public Works Department and the Albany Town and Shire planned the construction of a steep sided linear drain and excavation works were undertaken in 1961. In the steeper upstream reaches, ditches, armored banks and culverts have been relatively effective in confining storm water flowing from the slopes and transporting it to the lower catchment. A number of landowners along the floodway of the lower catchment consider that subsequent to the construction of the drain, maintenance works have been inconsistent and inadequate to address flooding issues.

The excavation and straightening of the channel reinvigorated erosion and depositional processes and this accounts for the undermining of banks, flood scours and deposition of sediment plumes. The clearing of native vegetation and disturbance of topsoil along the channels also facilitated the establishment of dense infestations of assorted weeds.

The extensive drainage works undertaken in the early 1960's did not address the flooding issue as expected and did not produce a particularly stable floodway. However, it did raise landowner expectations about local government custodianship of the channel and bequeathed an expensive maintenance demand on the City of Albany and by association, ratepayers.

The highly modified nature of the creek floodway plainly demonstrates that the conservation of natural waterway features and the associated riparian vegetation was of little interest to landholders in the historical management of this waterway.

Since the earlier works, studies regarding the management of Yakamia Creek have been dominated by concerns about the mitigation of flooding and local waterlogging. The occasional large floods have caused some problems and damage to infrastructure.

In the upper reaches of the creek, drainage works have focused on protecting roads and other infrastructure by moving storm water quickly downstream. In some sections flows have been piped underground and in others the channel has been lined with rock or concrete. However, sophisticated ways of managing the ecosystem in these areas have not eventuated, although some detention basin works have been constructed and two localised Living Stream projects have been undertaken in recent years.

The upper reaches of the creek pass through land set aside for public purposes, namely parkland, sports fields, and for passive recreation. Because of the public amenity profile of these areas there are reservations about undertaking rehabilitation works that may restrict the area available for the expansion of these facilities. The possible increased risk of local flooding is also of concern. Works to control storm water flooding in Dunn Park in the upper catchment have been criticised for taking up public open space. This highlights how different community interests can create conflicts and slow the planning and design process.

A 1981 Flood Investigation by the Public Works Department[1] estimated that some 12,000 cubic metres of sediment had been deposited in a 2.5 Kilometre section of the channel upstream of the Lower King Road during the twenty years since the initial channel modifications. This resulted in reduced discharge carrying capacity and where levees were in place the bed was raised above the floodplain further inhibiting efficient drainage. Steep bank batters in sandy soils also facilitated erosion. The exact origin of the sediment was uncertain, but was attributed to either bed and bank erosion in the steeper upper catchment or to various development works being undertaken

[1] "Yakamia Creek Flood Investigation Report" PWD Design branch, May 1981

immediately upstream of North Road. The Public Works Department estimated the cost for the drain maintenance at $109,000 for the Town and $113,000 for the Shire (1981 costs).

Following this, the Town and Shire Councils, Public Works Department, Minister for Water Resources, Crown Law Department and the Local Government Department held discussions on the problem of who, if anybody had legal responsibility for the status of Yakamia Creek and who should carry out the work – if anybody, and meet the costs. The Shire resolved in 1982:

"That the Yakamia Drain is considered to be a natural water course and that, as a result, whilst Council acknowledges its present condition, it takes the view that it has no obligation to expend the considerable amount of public funds requested to rectify the present situation."[1]

The City of Albany maintains this stance, although mutually agreeable solutions to drainage issues continue to be sought.

In 1989 the Water Authority commissioned Binnie and Partners Pty Ltd to undertake a further flood management study.[2] The emphasis once again, was on flood mitigation in the middle to lower reaches of the catchment and it was stated that over the previous 50 years the problem had gradually worsened (this was 28 years since the previous large scale drainage works). The causative factors were;

- Heavy siltation of the creek caused by sediments eroded from the steeper upper reaches of the catchment being deposited in the flatter lower reaches.
- Urbanisation in the upper reaches which had significantly increased the rate of runoff and the magnitude of flood peaks.
- Catchment clearing for farming which also increased the runoff rate and flood magnitude although not as significantly as urbanisation, and
- Lack of maintenance that had reduced the flow capacity of the creek.

The study recommended a number of actions and these included;

- Retention of a portion of the vegetated flood prone area as a 'bio-filter'.
- Flood protection provided by means of levees for rural lands situated outside the area set aside for the purpose of a bio-filter.
- Adequate flood-gated drainage outlets through levees designed for existing town drainage outlets between Martin Road and Lower King Road

The Water Authority had derived a design flow of 15 Cumecs[3] (approximately the volume of a VW Kombi van every second) with a conservative return period of 10 years (ARI)[4] and 25% of the catchment urbanised. The subsequent hydrologic modeling by Binnie and Partners produced a comparable value of 14.4 Cumecs at Martin Road. At that time flood modeling was based on the estimation that 25% of the catchment was urbanised and 25% was un-cleared, leaving 50% cleared or semi-cleared, but essentially rural. It should be noted that the 1989 study had no gauging data against which to calibrate their flood discharge model.

It was recognised that increasing urbanization would further alter the catchment discharge characteristics by increasing the area of hard surfaces and hence the rapidity of storm water runoff. This would mean more water, more often, moving more quickly along the creek line. As a result

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[1] Town of Albany File Notes: Report to Councillors from Director of Works and Technical Services. May 1990

[2] Yakamia Creek Management Study (1989) Report by Binnie and Partners Pty Ltd for Water Authority of WA.

[3] 1 Cumec = 1 cubic metre per second (1 m^3/s).

[4] A 10 year ARI flood means that in any particular year there is a 1 in 10 chance of it occurring.

further studies would be required to confirm or modify the calculations. It should be noted that that the detention/ bio-filter was never constructed since the Council resolved to support the concept on the premise that it would not be responsible for the maintenance of the filter.[1] Thus the search for cheap solution to an expensive problem continued.

In 2000, Green Skills undertook a survey of the condition of the channel and riparian vegetation along Yakamia Creek for the City of Albany and the then, Albany Waterways Management Authority. This represented a first holistic environmental assessment of the condition of the riparian areas of the modified creek. The recommendations of the assessment advocated adopting a more 'natural' stream form with vegetated foreshore buffer zones up to 60 metres wide. The weed management issue was also identified as a critical factor for the health of the system. However, no clear definition of what constituted a 'natural form' was specified

In 2001 the Department of Water (Water and Rivers Commission)[2] undertook a further flood study to refine design flood flow estimates for Yakamia Creek. Two stream flow gauging stations had been constructed in the early 1990's to provide real data that could be used to calibrate the URBS-CM hydrologic model. The two gauging sites were located at North Road and the Lower King Road. The North Road site (now destroyed by stream flows) provided 8 years of data, but this was not sufficient to provide a flood frequency analysis.

It was noted that during the 8 year period from 1993 to 2001 the largest flood flow recorded was 4.8 cubic meters per second and that was recorded on 29 August 1998. The Lower King Road gauging site yielded intermittent data with a continuous record only available for the period 1998 to 2000.

The hydrologic model yielded some estimates of the way in which the creek responds to various storm events. Flood discharge was estimated for 2, 5, 10, 25, 50 and 100 year average recurrence interval storm events.

Analysis of the likely duration of the ARI events indicated a period of 72 hours with a lower secondary peak flow at around 36 hours. For all model simulations the critical duration of the flood at the Lower King Road was around 36 hours. The duration figure of 72 hours was adopted as the critical duration.

During April 2005 the catchment experienced two major storm events within a twenty-four hour period. These caused widespread flooding and were initially estimated to represent a 1 in 100 year ARI rainfall event. In 2006 Opus International Consultants Pty Ltd, undertook a flood analysis of this event for the City of Albany. This enabled flood management maps to be produced for 10 and 100 year design storm events and a Flood Management Plan (2007)[3] was developed to guide future urban expansion. A number of significant deficiencies in the existing storm water drainage system were also identified.

Some landholders have expressed frustration that these hydrological studies seem repetitious and were avoiding the need for on ground actions. In reality the studies represent improvements in methods to assess the flood runoff characteristics of the creek system. One problem is that the catchment characteristics are continuously changing with urban development. This means that flood studies gradually become out dated. Flood runoff modeling does not offer solutions to flooding

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[1] Town of Albany File Notes: Report to Councillors from Director of Works and Technical Services. May 1990.

[2] Department of Water (2001) "Yakamia Creek Flood Study" Unpublished report Hydrological and Water Resources Series HY 06 2001.

[3] Opus International Consultants (A. Vanceva) 2007, *City of Albany Flood Management Plan: Yakamia B Catchment* Report for City of Albany.

problems, but is essential to provide sufficiently accurate data for designing proposed drainage solutions.

The bottom line message for Living Stream projects, as for traditional drain design, is that works in the floodway need to be robust enough to easily handle flood discharges that tend to occur at 2 to 5 year intervals and be able to recover from larger storm events. In addition, Living Stream works should be designed to ensure they pose no more of a problem than standard drains. The 100 ARI peak discharge thus represents a conservative design parameter.

These requirements imply that qualified engineering design input will be mandatory for all project proposals along the creek, as they were for the Barnesby Drive stream rehabilitation site.

The Oyster Harbour Catchment Group was formed in 1992 and became an incorporated body in 1994. Its primary focus has been natural resource and it has been very successful in attracting significant funding for waterways protection measures, but it was only in 2012 that more attention was focused on the King River and Yakamia Creek catchments.

The City of Albany and various other stakeholders have in more recent times considered the role of the creek system in providing other community services. These services include, improved water quality, visual amenity, passive recreation, city ambience and ecological function through the protection and where possible, reinstatement of local flora and fauna species and the provision of suitable habitat for their maintenance. The potential impacts of the discharge from Yakamia Creek, on water quality in Oyster Harbour, is also becoming an important issue. However, such innovations are currently minimal. Some rehabilitation was undertaken adjacent to the Yakamia Primary School in the 1990's, although this involved re-vegetation using non-local trees. A benefit of this work is that it showed how re-vegetation could affect the creek environment favorably. The Barnesby Drive and Sanford Road Living Stream projects have introduced the community to the concept of Living Stream development based on careful design for integrating storm water management and ecosystem function. Community events to assist with weed management at the Barnesby Drive Living Stream site have been encouraging, with people showing an interest in the project.

Community management concerns

Stormwater flooding, traffic movement and public amenity appear to be the main community concerns along the upper catchment floodway. In the middle reaches flooding is of some concern along with weeds and waterlogging. The primary desire of landholders along the lower reaches of the creek, given the semi-rural nature of the larger properties, is to have adequate drainage to alleviate flooding and waterlogging. This issue dominates discussions on the management of the creek in these areas.

Following the initial restructuring of the creek line from a natural floodway to a linear drain in 1961, management efforts have tended to be reactive and sporadic and hindered by a preoccupation with localised problems and arguments about who is responsible for what.

The 'fix-all' solution generally offered is the enlargement and regular 'cleaning out' of the existing channel, preferably at the expense of the City. This suggests some community appreciation that a holistic rather than piecemeal management approach is needed. While excavation can improve flood flow it should be noted that a larger and supposedly more efficient channel was the goal of the 1961 drainage works. It begs the question, why didn't those works deal with the problem of flooding, erosion and excessive sedimentation? The lower reaches of Yakamia creek are a broad, natural flood zone and have a very low slope as well as coming under the influence of tides in the lower reach. These factors place physical limitations on the discharge conveyance efficiency of any excavated channel.

The goal of more consistent and efficient management of the middle to lower floodway that passes through many private properties is achievable, but will require a compromise regarding land

development. This is the finding of Melanie Price (2013)[1] in the urban development plan for the Yakamia/Lange precincts. It will in turn require the creation of a more detailed foreshore concept plan for the floodway from North Road to Oyster Harbour, including the associated tributaries. This should be based firmly on catchment hydrology and proper functioning condition, in an ecological sense, of the floodway. Landholder consensus and commitment and a durable memorandum of understanding between all stakeholders will be essential for the best management of the creek environs. Unfortunately this is currently lacking.

Community consultation – clear messages

A community meeting was undertaken on the 14th of October 2014. The focus was the catchment downstream of North Road. The meeting was attended by 22 landholders after 63 invitations were sent out. The meeting was chaired by Louise Duxbury and presentations were given by Steve Janicke (on the geomorphology of the creek), Karen McKeough (from DOW, on the water quality of the creek) and Jonathon Bilton (from Oceans Foods, on the importance of water quality for the aquaculture industry).

The primary concern and frustration of the attending landholders was that they wanted to know why their houses and sheds flood 'all the time' and why 'someone' wasn't doing something about it. Weed control was also considered important for various reasons, mainly the vegetation encroachment into the drain thus reducing its efficiency.

Attending landholders from the broad low-lying areas were generally of the opinion that "There is no need to call it a creek anymore: it is now the Yakamia Drain." Their reasoning was, "when the drain was dug in 1959 it did not follow the creek so it is no longer a creek. Thus having created a drain, it was the Councils responsibility to maintain it." The question of who was responsible for the creek was answered in part by Austin Rogerson (drainage engineer, CoA) that since the creek runs through private property, it is the responsibility of the landholders. It is not vested as a reserve or an easement with the CoA. In this respect it is different to Robinson Drain which is a Water Corporation drain with an easement over the land and comes under a drainage Act. This issue has been on-going since the late 1970's with a then Town of Albany Council resolution in December 1983 "That the Yakamia drain is considered to be a natural water course and that, as a result, whilst Council acknowledges its present condition, it takes the view that it has no obligation to expend the considerable amount of public funds requested to rectify the present situation."

Yakamia Creek as a Living Stream

*"Yakamia Creek and its tributaries provide a significant district ecological connection to Oyster Harbour and beyond. Connectivity associated with these features should be retained and strengthened through provision of adequate buffers and rehabilitation of degraded areas". (*Melanie Price (2013)[2] Aurora Environmental*)*

In practice, stream rehabilitation projects that are suited to Yakamia Creek will vary in nature and degree from section to section. At the high end, the Living Stream model reinstates many of the features of natural stream form and at the low end, limited enhancement is undertaken in order to achieve one or two specific outcomes. Some of the potential outcomes of projects are as follows;

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[1] Melanie Price (2013) *Yakamia Structure Plan Area, City of Albany Environmental Assessment - Opportunities and Constraints*, Report No. AA2012/020 by Aurora Environmental for the City of Albany

[2] Melanie Price (2013) *Yakamia Structure Plan Area, City of Albany Environmental Assessment - Opportunities and Constraints*, Report No. AA2012/020 by Aurora Environmental for the City of Albany

Rehabilitation providing and sustaining ecosystem function includes;

- The maintenance of native flora and fauna species.
- Nutrient and bacterial bio-filtering to improve water quality
- Increased rainfall infiltration into the groundwater system
- The provision of shade to reduce algal growth.
- The provision of shade to control certain weed species.
- Improved air quality.

Rehabilitation providing community services includes;

- Provision of passive recreation opportunities.
- Enhanced visitor and tourist experience.
- Improved quality of life and mental health of residents.[1]
- Improved property values.
- Enhancement of sporting environs.
- Engagement of the community in effective urban water management
- Provision of an educational resource for students
- Suppression of ambient traffic noise.
- Demonstration of progressive urban water management.
- Increase capacity for urban water harvesting in the future.
- Reduced need for parkland irrigation and mowing.

The conveyance of water through the urban landscape along Yakamia Creek offers social and environmental benefits besides the mitigation of the occasional inconvenient flood or local waterlogging. These benefits have valid economic, social and ecological implications providing so-called, *ecosystem services*. People, it must be said, are also included in the living ecosystem. In addition, Yakamia Creek flows into Oyster Harbour and this is a recognised and well-used natural asset to the Albany community and should be maintained in good condition. Although Yakamia Creek represents less than 1% of the total catchment area draining into Oyster Harbour its influence is not insignificant with respect to water quality and the consequences of pollution.

Most streams support living organisms to a greater or lesser extent and the chief aim of a Living Stream development, unlike a drain, is to increase the diversity of plants and animals, including a host of less obvious organisms such as fungi and microorganisms that underpin ecological processes. The degree of biodiversity is ultimately dependent on the physical structure of the floodway and the quality of the water flowing through it. Increased biodiversity can also provide a check on the proliferation of unwanted animal and plant species.

Nevertheless, it would be unrealistic to set the goal for Living Stream projects along Yakamia Creek to: *reinstate the original natural stream form*. In the Albany urban environment, human activity has fundamentally altered the pre-settlement ecosystem. By covering the catchment with impervious surfaces such as roads, buildings and paving, the storm and groundwater runoff pattern for the entire catchment has been dramatically changed and many of the changes are effectively irreversible. The original floodway form would no longer match the new runoff characteristics.

Drain characteristics can be simply described and measured, but 'natural' streams, by virtue of their complex channel geometry and riparian vegetation characteristics, are much harder to describe and therefore to reconstruct and manage. This management plan does not attempt to define an ideal

[1] Findlay S.J. and Taylor M.P (2006) *Why rehabilitate urban river systems?* Area: 38.3 312-325 Royal Geographical Society (with The Institute of British Geographers)

channel form or natural stream environment for reaches of Yakamia Creek. Rather it considers what waterway attributes may help enhance the ecological function of the drainage system, within the constraints imposed by urban development. The durability of these enhancements will, in turn, define what a successful stream rehabilitation project means in the context of the urbanised catchment. There will be an element of experimentation required and the monitoring of projects outcomes over time should attempt to answer the questions, "What worked, what didn't work and why?"

Principles of Living Stream design

The concept of Living Streams rests on the premise that a linear drain in an urban environment may be restructured and enhanced with natural features without compromising its stormwater conveyance role. Drain design has generally been dictated by ease of construction and upfront cost. Properly engineered for both low flow and floodwater conveyance, the floodway can be managed in a way that minimises erosion and sedimentation (hence ongoing maintenance costs) by adopting a natural cross-section, enhancing sinuosity and using native vegetation to stabilise the channel (soft engineering). That is what nature does.

Living Stream design goes beyond urban stormwater conveyance, to create riparian and aquatic habitat for living things, both plants and animals and by association, people. Done well, Living Streams achieve multiple outcomes, including the fostering of a healthier urban ecosystem, improved water quality, effectively conveying floodwaters and creating attractive landscape features for the residential community and visitors (Water and Rivers Commission, 1998[1]).

The term 'stream restoration' is often used for projects aimed at preserving a natural environment, but restoration implies returning a system to its original condition. The urban Living Stream concept is better described by the phrase *stream rehabilitation* or *ecosystem enhancement* (Findlay and Taylor. 2006[2]). This suggests the possibility of reinstating some aspects of the original stream ecosystem, but predominantly it means improving stream attributes and controlling adverse degrading processes.

The aims of Living Stream rehabilitation are therefore;

- To reintroduce some critical attributes of natural stream function (not necessarily the original) in selected reaches, if not over the entire length of the stream, for ecological and social benefits.
- To create attributes that are compatible with existing and likely future urban development.
- To influence other development plans to incorporate environmental values.
- To protect any remaining natural attributes of the drainage system where possible.

Living Stream retrofitting is designed to achieve desirable environmental outcomes as well as allowing for community interests such as sport, passive recreation and pedestrian thoroughfare, without compromising the essential urban stormwater drainage function of the creek.

In order to gain insight into the nature of urban constraints and to evaluate the potential for Living Stream development along Yakamia Creek, it will be helpful to begin by reviewing the physical attributes of a simple engineered open drain.

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[1] Water and Rivers Commission 1998b, *Living Streams,* Water Facts 4, Water and Rivers Commission, Perth, Western Australia.

[2] Findlay S.J. and Taylor M.P (2006) *Why rehabilitate urban river systems?* Area: 38.3 312-325 Royal Geographical Society (with The Institute of British Geographers)

Drains

The function of most drains is simply to convey water from point A to point B as quickly, efficiently and cheaply, as possible. Other stream functions are not generally considered a priority. The usual reasons for designing such a drain are; first to control damaging floods and secondly to reduce waterlogging in developed areas or in land earmarked for development. A hydraulically efficient drain is designed to have a simple geometric cross-section constant along its length with relatively 'smooth' bed and bank surfaces and a uniform lengthwise slope. A common drain profile is trapezoidal, having a flat base and straight, steeply sloping banks. Any hindrance to the uniform flow of water reduces the efficiency of the drain and these are avoided in designs. Nevertheless, in urban environments such impediments are common and include road crossings, culvert pipes, sediment deposits, sudden drops in bed level (drop structures, Figure 11), encroaching vegetation (often weeds), effluent discharge points, changes in drain cross-section and accumulated detritus and rubbish.

Figure 11: Drop structure on Yakamia Creek in section D2.5

Drains are designed to limit the inherent physical characteristics of moving water, by fixing the geometry of the channel. This type of control is illustrated by the armoured section of Yakamia Creek adjacent to the Cricket grounds at the western end of Centennial Park Sporting Precinct (Figure 12). However; in natural streams water flow acts to construct and shape the channel.

Figure 12: The armoured section of Yakamia Creek at the western end of Centennial Park Sporting Precinct, July 2011.

Natural streams

In contrast to a simple engineered open drain, natural streams exhibit complex curvature of the dominant channel, the floodway and the extended floodplain. The cross-sectional area and shape reflects the diversity of storm flows and groundwater discharging from the catchment. This results in highly variable cross-sectional geometry. There are a number of common features of the cross-section of a stream, although not all need be present depending on the overall valley shape. These features include the dominant channel, fluvial terraces or benches, the floodplain and riparian verge. Figure 13 shows an idealised cross-section with these features. The bed slope is also variable, a result of geological formations and water alternatively speeding up and slowing down along its path. The bed and bank surfaces vary in 'roughness' depending on the soil type, the diversity and density of vegetation and assorted subsurface features including the geological foundation of the landscape.

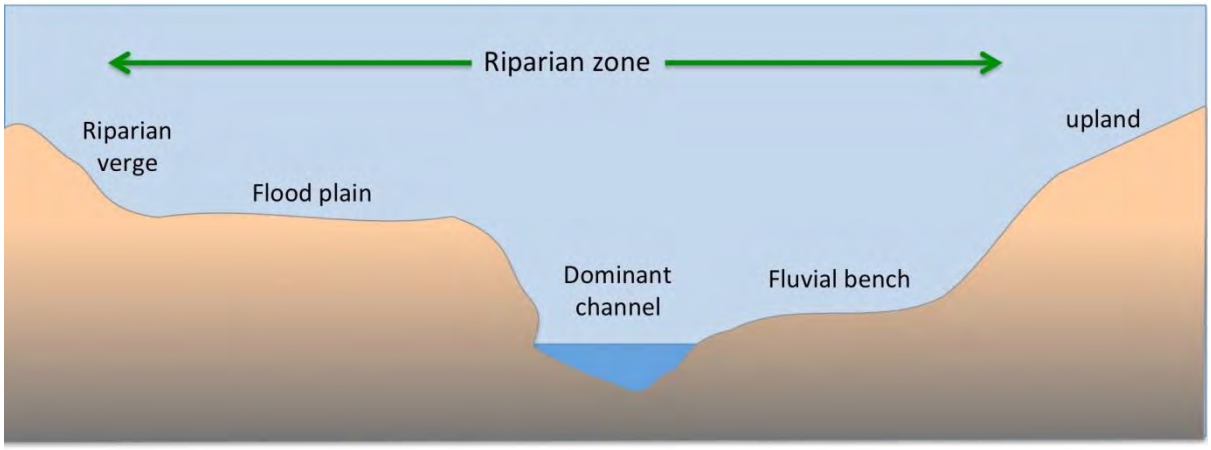

Figure 13: Common features of an idealised cross-section of a stream.

Living Streams are constructed channels designed to mimic natural streams, with high flows accommodated along the vegetated streamline and its floodway (Department of Environment and Swan River Trust 2006[1]). Low flows are also functional in an ecological sense, serving to create and maintain habitat diversity. Healthy fringing vegetation provides shade, wildlife habitat, ecological corridors, erosion control, recycling and bio-filtration of pollutants.

Stream energy is dissipated unevenly along the channel and this equates to the development of many localised channel features such as pools, riffles, knickpoints[2], waterfalls, bank scours, bends, point-bars, sediment plumes, fluvial terraces or benches, bank undercuts, accumulations of bed material, deadwood, silt, sand and rocks. Natural streams generally take up more space than drains and this partly explains the pressure to straighten them or to pipe them underground. Many features that are considered a problem for engineered drains are acceptable attributes of natural channel form.

Hydraulic attributes of channels (the key to management)

Channel attributes of bed-slope, cross-sectional area, surface roughness and water velocity are the key factors that help define the overall hydraulic character of both natural streams and engineered drains. In all streams, these basic attributes are interdependent and influence each other to form the distinct features we associate with rivers and creeks, large and small, worldwide. In other words, if one attribute is modified, others will tend to readjust according to the frequency and intensity of rainfall runoff events from the catchment. Thus weather patterns play a crucial role in determining long term stream form.

Water flowing along an unarmoured drain will act to reconstruct natural channel features.

Considerations on what constitutes appropriate management should take all of the catchment into account. This is chiefly achieved through undertaking hydrological studies to determine how much water is falling on the catchment and how much is flowing through it, as well as how often and how

[1] Department of Environment and Swan River Trust 2006, *Retrofitting, Storm water Management Manual for Western Australia,* Department of Environment and Swan River Trust, Perth, Western Australia.

[2] A **knickpoint** is a term in geomorphology to describe a location of a river or channel where there is a sharp change in channel slope, such as a waterfall or lake.

strongly. The various flood studies undertaken for Yakamia Creek were done in order to understand the pattern of catchment runoff, not to specify a solution to flooding problems, although the information is essential for solutions to be found. Sediment eroded from the tributaries as well as the bed and banks of the main channel, is transported to the lower reaches and deposited in the low gradient parts of the channel and on the flood plain.

The most critical attribute of a stream section, from the point of view of designing rehabilitation works, is having enough space to carry them out. This is often described as providing an adequate foreshore 'buffer'. A question often asked is how wide should a foreshore buffer be to be adequate? Unfortunately, arbitrary foreshore buffer widths rarely match the varying morphological attributes of the riparian areas. It is suggested that the word buffer be replaced by the less defensive words, riparian zone. In order to achieve a realistic outcome, an appropriate foreshore riparian width must be determined locally, by considering the spatial dimensions of the floodway zone on a section-by-section basis. Important factors include the valley profile, whether it is V shaped with confined flow or shallow with a broader floodplain, as well as the likely extent of various floods and the subsurface and groundwater sources.

In summary, the geometrical attributes of a natural stream reflect the intrinsic interaction between a wide range of rainfall runoff events and the soils that compose the floodway. A simple drain is often constructed largely to try and handle major floods; and this sums up the current status of much of Yakamia Creek.

Water Sensitive Urban Design

Water Sensitive Urban Design (WSUD) is the integrated design of the urban water cycle, incorporating water supply, wastewater, stormwater and groundwater management and environmental protection. WSUD aims to see all streams of water being managed as a resource, as they have quantitative and qualitative impacts on land, water and biodiversity, and the community's aesthetic and recreational enjoyment of waterways[1]. There are various stormwater management techniques available that integrate public open space, water quality and environmental enhancement objectives which are described in detail in state and national publications. Supplement 1 of this report presents a number of case studies that are very pertinent to future Living Stream projects along Yakamia Creek.

Retention and Detention basins and Bio-filters

This report suggests the use of detention basins with bio-filters (constructed wetlands) that are compatible with the objectives of Living Stream projects. These built structures help retain the function of floodplains wherever the former extent must of necessity be restricted.

The two urban storm water structures that can be integrated into Living Stream projects are retention and detention basins. A *detention* basin is an area of low lying ground adjacent to or associated with the path of stormwater and is designed to intercept and slow storm runoff to lessen the impact on downstream areas. A *retention* basin traps water in a pond, lake or wetland associated with a stream and the water eventually seeps (infiltrates) into the ground or is lost to evaporation and evapotranspiration. The groundwater system naturally acts to detain and retain rainfall.

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[11] BMT WBM Pty Ltd (2009) *Evaluating Options for Water Sensitive Urban Design (WSUD) – A National Guide*. Guidelines developed in accordance with National Water Initiative Clause 92 (ii) for the Joint Steering Committee for Water Sensitive Cities

These two types of basin emulate the wetlands, backwaters and groundwater we associate with natural stream systems. They function to strip nutrients and other contaminants from stormwater and therefore improve the water quality. For this reason they are increasingly used in urban environments. In a Living Stream sense retention and detention basins become *constructed wetlands*. Traditionally, wetlands have been viewed as a liability, only suitable for landfill in the same way as creeks have been viewed simplistically, as drains.

Since vegetation is used to do the nutrient stripping both retention and detention basins can act as *bio-filters* however the bio-filter function is most efficient at processing low flows. A simple detention area is designed to divert flood flows into a basin and release the water slowly, while low flows and excess flood flows pass down the main channel. A detention basin with bio-filter function diverts low flow and the initial flood flow into the basin while excess flood flows pass down the main channel. Figure 14 below illustrates the two potential functions of a detention basin. The hydraulic operation of each with respect to low and high flows in the stream is fundamentally different. Placing a detention basin in the main steam channel is a possibility, but the risk of flood damage to any bio-filtration features in increased.

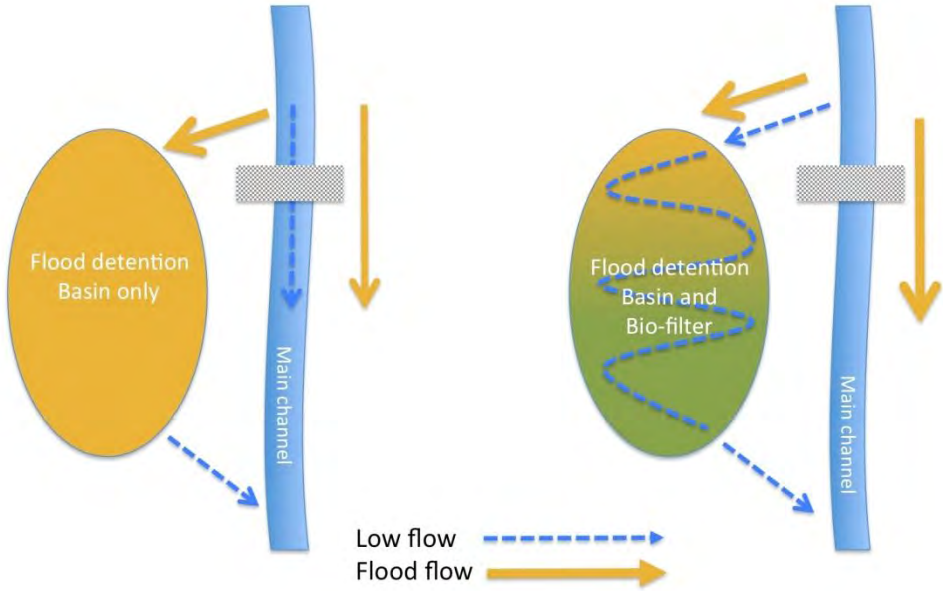

Figure 14: Comparison of the conceptual flow paths for floods and low flows using a detention basin and a detention basin plus bio-filtration function.

Constructed wetlands can also provide a diverse habitat for supporting plants and animals as well as be designed to provide a pleasant park environment with various social amenities. Case Study 7: Toowoomba West in Supplement 1 illustrates a flood detention and bio-filter basin. Constructed wetland design for Yakamia Creek is discussed a little more under the heading, 'Concept plans for selected Tier 1 targets'.

Water quality monitoring at a number of locations in Yakamia Creek indicates that levels of nutrients, minerals and bacteria exceed recommended levels for a healthy stream environment. For this reason it is suggested that provision of both floodwater detention and bio-filtration of low flow stream discharge along Yakamia Creek needs to be considered wherever it is feasible to do so, even if this means modifying the existing channel infrastructure.

Drains that are designed to move stormwater along the channel as quickly as possible offer no opportunity for improving water quality via vegetative bio-filtration.

Three areas in the upper catchment are considered as offering significant opportunity for constructed wetlands, Dunn Park, Bevan Road and the western end of Centennial Park Sporting

Precinct (downstream of the intersection of North Road and Barnesby Drive). Other sections also qualify, and are discussed in this management plan. There is also opportunity for the provision of small-scale bio-filtration and infiltration installations at domestic and industrial sites. These are especially appropriate if they can be placed as near to the source of stormwater as is feasible. By re-directing localised rainfall runoff into areas where it can infiltrate into the ground, the risk of flooding downslope can be significantly reduced. These WSUD options are not developed in this management plan.

Living Stream maintenance

The successful rehabilitation of a waterway to create a Living Stream is a long-term process and requires a maintenance plan to contribute to the success of a project. Maintenance activities may be needed more frequently during the initial establishment phase[1].

Common maintenance issues include:

- ease of access to sites,
- repair of minor damage to the in-stream restoration features following bigger floods (e.g. rock displacement from riffle, riprap and chute, bed and banks erosion, sediment accumulation, damage to the existing banks vegetation},
- growth of weeds, inadequate plant establishment or excessive establishment,
- regular maintenance of pre-treatment features (such as filter strips or litter and sediments traps etc.),
- if a project is undertaken by a contractor or developer, the maintenance responsibilities can change after the agreed warranty period ends,
- changing pressures and impacts from nearby developments, e.g. revised zoning, change of land ownership, changes in business.

Some maintenance observations from the Department of Water[2]:

- Bed and banks stabilising structures such as riffles, chutes, riprap, large woody debris etc. should be inspected at least annually and if possible after each heavy flood. If problems appear, maintenance should be performed promptly to prevent potential costly damage.
- During the initial stage when the vegetation has not fully established, there may be a high risks of banks erosion or slumping. Such erosion can extend rapidly, so should be controlled as soon as possible. However, it is important to investigate the reason for the erosion so that appropriate measures can be implemented.
- A visual inspection of flow patterns (during low and high flows) on waterways, vegetation establishments, vandalism (to infrastructure or vegetation) etc. can assist with promoting better understanding of problems.
- Regular or long term maintenance issues may be litter collection, sediment or debris removal and weed control.
- If the site experiences high sediment deposition and/or high litter problem, an in-stream sediment trap (e.g. a riffle or a pool) and/or a gross pollutant trap at the upstream of the Living Stream site can be installed.
- Community ownership to the project can play an important role in the short and long term maintenance, especially when the area has public access for recreational purposes.

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[1] Department of Water (April, 2011), *An overview of living stream project: initiation to implementation.*

[2] Department of Water (April, 2011), *An overview of living stream project: initiation to implementation.*

- A newly vegetated site should be checked every two weeks for the first six months to allow early detection of germinating weed species and assessment of the success of plantings; supplementary planting may be required.
- A concentrated focus is required on the weed control in the first two to three years unless the native vegetation is fully established.
- Some selective thinning of vegetation may be required to restore the flood conveyance capacity of the channel. Clearing of significant debris dams, disoriented woody debris, culvert blockages etc. should be undertaken to maintain the capacity of the channel.
- Additional introduction of habitats (including introducing aquatic animals) may be required if habitat improvement is not satisfactory.
- Depending upon the nature and location of the site, the responsibilities of inspection and maintenance can be shared with the local communities and/or any other relevant stakeholders.

We have observed too frequently, money, effort and volunteer hours being negated by overspray and indiscriminate use of herbicides to control weeds. One aspect of the failure of the Paterson St. "Living Stream: project (see Case Study 6 in Supplement 1) is that native seedling regeneration could not occur, being sprayed out whereas annual grasses reoccurred each year. It is important for the longer term success of a Living Stream project that regeneration of riparian plants through germination and seedling growth be allowed to occur. Preference should be for 'Friends' groups to weed by hand. Training of staff operating spray units tends to focus on health and safety considerations for the operator. Maintenance operators also need training in discerning and valuing native vegetation and their seedlings.

Yakamia Creek Living Stream opportunities – assessment methodology

Two overarching factors underpinned the method for determining what sections of the Yakamia Creek system offer opportunities for Living Stream development. These were;

- Existing section attributes.
- Constraints on potential section modifications.

Existing section attributes defined the nature of the local riparian ecosystem and constraints here mean; limitations imposed on any proposed floodway enhancements. Each of the overarching factors was qualified by a number of criteria. The measure for each criterion consisted of a number of features for which presence or absence could be established at each stream section. The approach was not to create a 'scientific' formula that would choose likely project sites, but to ensure that constraints were systematically examined for each section and the implications for rehabilitation options evaluated. The final score of features was used as a justification for rehabilitation feasibility. Various levels of rehabilitation are possible and what could be applied to a particular section will depend, not only on constraints, but also on other management objectives that may be identified.

Assessment of current channel form, issues and Living Stream opportunities

The purpose of the channel assessment was fourfold as follows;

- To identify the physical and vegetative characteristics of discrete sections of the main stream channel and selected tributaries.
- To determine what constraints would apply to any attempted modifications.
- To determine where opportunities might exist for stream enhancement projects.
- To determine what those opportunities are.

In addition geo-referenced photo points were established to assist with tracking changes to sections over time. The photo point audit is included as Supplement 2 to the Yakamia Living Stream Management Plan.

The study sections

The parts of Yakamia Creek that were of primary focus in this report consist of 15.5 Kilometres of channel, divided as follows;

- 9.4 Kilometres of the main channel of Yakamia Creek between Anson Road and Oyster Harbour,
- 6.1 Kilometres of tributary.

The channels were divided into seven zones each reflecting their position in the catchment. Zones were then divided into sections. Typically, section ends have been determined by road crossings, a change in land tenure, different land uses, necessary drain function or other noticeable change in channel form. 108 sections were identified, a number that indicates to some extent the level of fragmentation of the creek. The zones are described in Table 2 and shown on the map in Figure 15.

Maps 1 to 11 in

APPENDIX 2 define contiguous sections of the main channel of Yakamia Creek (86 sections) and 4 key tributaries (22 sections).

Table 2: Division of the channels of Yakamia Creek.

Zones	Length (kms)	Description
Yak _A	1.6	Between Anson Road and Chester Pass Road
Yak _B	1.1	Between Chester Pass Road and North Road and adjacent to Barnesby Drive.
Yak _C	2.8	North Road around Centennial Park Sporting Precinct and including the tributaries from Albert Street and Knight Street.
Yak _D	4.3	North Road / Sandford Road to Lower King Road
Yak _E	2.1	Lower King Road to Oyster Harbour
Yak _F	0.9	Callistemon View tributary
Yak _G	2.8	Lange tributary

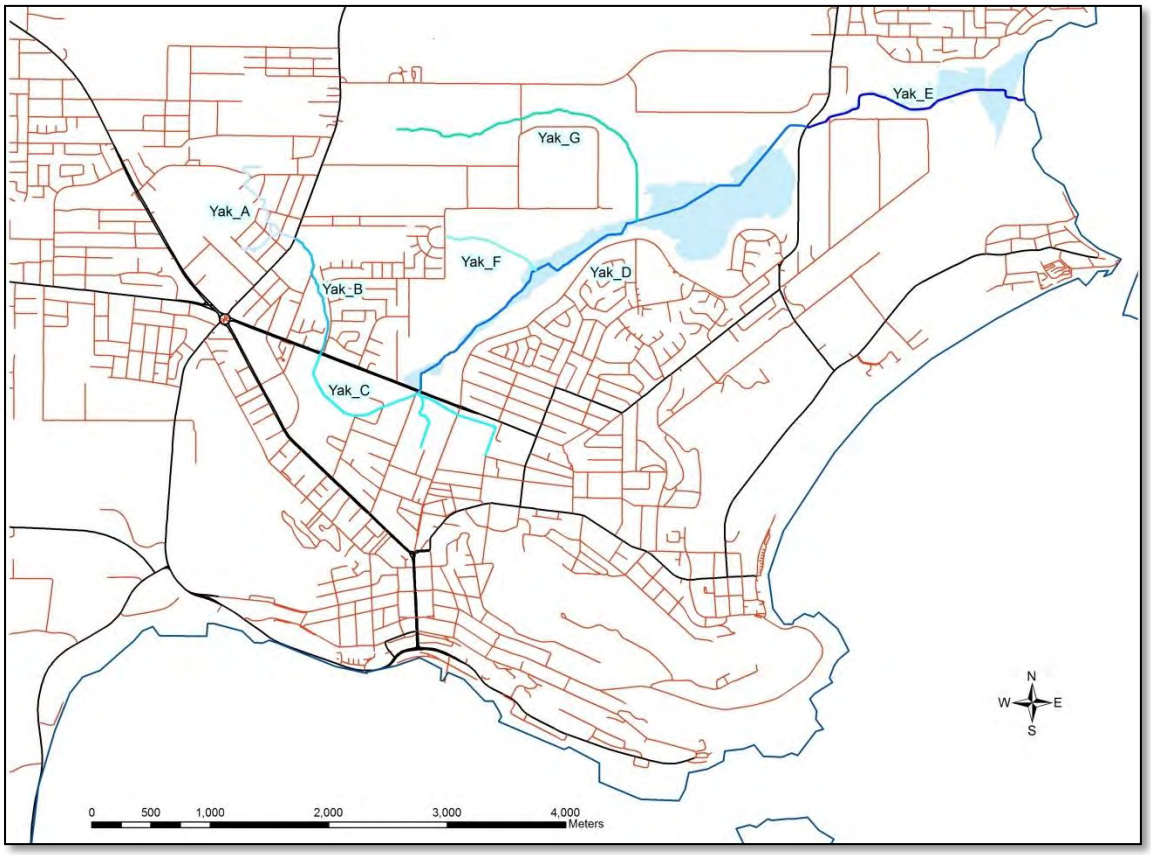

Figure 15: Study zones of Yakamia Creek.

Determining project opportunities along Yakamia Creek

Opportunities for Living Stream projects are subject to qualification and three primary levels of intervention are suggested;

A. Reconstruction of the floodway and riparian attributes at the section scale. For example;
- ◊ Redesigning channel cross-sectional form and bed slope features.
- ◊ Recreating channel sinuosity.
- ◊ Creating wetland zones (including ponds, retention and detention basins).
- ◊ Re-vegetating an entire section with an adequate foreshore riparian buffer.

B. General enhancement or protection of existing riparian attributes. For example through;
- ◊ Weed management.
- ◊ Re-vegetation of degraded areas with native species.
- ◊ Localised bank and bed stabilization.
- ◊ Introduction of rock or logs to increase habitat diversity.

C. The introduction of basic ecosystem features for specific, but limited reasons. For example;
- ◊ Construction of riffle zones for aeration of water.
- ◊ Patch re-vegetation for shading.
- ◊ Creating nutrient stripping areas to improve water quality.
- ◊ Intercepting water near rainfall source to promote soil infiltration.
- ◊ Adding some visual amenity, e.g. planting a few trees.
- ◊ Limited weed control.
- ◊ Repairing aging infrastructure.
- ◊ Relocating stormwater drains.

D. No modification (do nothing).

Constraints on environmental rehabilitation were rated according to the criteria defined in Table 4 and Table 5 below. The rating provided a justification for why a section may or may not be suitable for Living Stream development and if so, to what extent. The fewer constraints there are the greater the opportunity to undertake more significant levels of rehabilitation. The section ratings are meant as a guide only since other external factors may favor or exclude one or more sections. For example several connected sections may warrant priority attention over isolated sections with fewer constraints. The final decision about which section(s) offer the best opportunities should be a joint decision between the key stakeholders. It may be noted that minor impediments such as the location of a fence or a path were not considered to be valid impediments to sound environmental management of the creek system in the medium to long term.

Public lands and particularly undeveloped or partly developed areas tended to score lower in terms of constraints, and sections constrained by infrastructure and private tenure tended to score the higher.

The minimum constraint score across all nine criteria was zero and the maximum was 27. In order to short list sections for further consideration, the scores were grouped into one of four tiers of potential intervention. These are outlined in Table 3.

Table 3: The four tiers of potential Living Stream project opportunities.

Tier	Constraints rating	Action
1	0 - 5	Initial, feasible targets for Living Stream rehabilitation
2	6 - 10	Future potential, but with one or two significant issues to take into account.
3	11 - 20	Problematic, with multiple development issues to consider
4	> 20	Highly constrained (do nothing)

For details on how sections were scored see APPENDIX 1: Constraints scoring for each section of Yakamia Creek. Table 6 below is a grouping of these results into the initial preferred and feasible targets (Tier 1 sections) and summarises opportunities, objectives and design considerations for retrofitting. The isolated sections in Tier 1 provide smaller project opportunities, but rehabilitating a group of connected sections offers larger scale ecological and social outcomes and these reaches are favored opportunities for medium term (2 – 5 years) projects. It is also suggested that when developing rehabilitation projects in target sections, due consideration should be given to the way in which the works may connect to upstream and downstream sections and whether there are ways constraints can be removed or lessened in the future. The approach should be to review the importance of any Tier 2 sections immediately upstream and downstream of proposed project areas.

Table 4: Constraints on Living Stream development in an urban environment

Constraint	Interpretation	Assessment criteria
Area of riparian space available	The lateral and longitudinal extent of the stream channel determines the scope of designed works that is possible. Insufficient space will limit development or render it inappropriate.	Section length. Width available for riparian vegetation.
	Lateral confinement, typically found along linear urban drains, provides less opportunity for introducing natural stream sinuosity and associated habitat for increasing biodiversity, both aquatic and terrestrial.	Opportunity to add channel sinuosity.
	The character of the channel immediately upstream and/or downstream of a target section may also limit ecological connectivity and development. Nevertheless, short sections or patches are not necessarily excluded and can contribute to the overall condition and health of the waterway.	Section connectivity with reaches upstream and downstream.
Optimum Stormwater conveyance	Urban stormwater management requires that Yakamia Creek channel adequately accommodates peak discharges that typically recur at 5 year (Moderate flood) and 100 year (Major flood) intervals.	Capacity to alter channel cross-section.
	Stormwater conveyance may be the only allowed function for a section of urban stream channel. For example some sections are piped underground with no feasible alternative.	Conveyance stormwater infrastructure.
Land tenure issues	The willingness of the landowner to participate in Living Stream rehabilitation is crucial to whether the project even gets started. Land titles confer rights to landowners and custodians to use and modify waterways without detriment to upstream or downstream users. However, the diversity of values, aspirations and opinions generally hinders a consistent approach to management along an entire stream reach. Living Stream project aspirations may be (and often are) thwarted by lack of agreement between stakeholders, even to the extent of making the 'do nothing' option, the only option.	Land Tenure
Public Amenity	Streams contribute to the quality of an environment and the quality of resident and visitor lifestyle. They can also improve local economic values through tourism and real estate valuations. Drains may pose public safety and health risks while providing their basic service.	Public Amenity.
Maintenance Issues	The presence of infrastructure such as power poles, other drains, adjacent buildings and crossings will not only constrain what works can be undertaken, but the ease of ongoing maintenance of a section. This constraint relates strongly to the need for adequate riparian space to construct and maintain stream ecosystem characteristics. Low maintenance attributes of Living Stream projects are desirable factors to be included where possible in the design phases of projects. Hindrances to channel maintenance limit Living Stream proposals and works.	Equipment/ machinery/ personnel access.

Table 5: Constraint criteria

Scoring for constraints to Living Stream development	0 = No constraints	1 = Some constraints	2 = Moderately constrained	3 = Highly constrained
Section length score	Greater than 100 metres	50 -100 metres	30 - 50 metres	Less than 30 metres
Riparian connectivity up and down stream	Continuous up and down	Crossing culvert one end	Crossing culvert two ends	Piped either end or both ends
Capacity to add channel sinuosity.	Full meander plus	Full meander	Half meander	None
Width available for riparian veg.	Full flood way	Dominant channel bed and bank plus 2 - 30 m either side. Fluvial terraces	Dominant channel bed and bank plus up to 2m either side	None
Capacity to alter cross-section	Unrestricted cross-section modification	Slope and fluvial terraces	Reduce bank slope	none
Stormwater conveyance infrastructure	None	Lateral pipe inputs and /or drop structures mid-section	Armoured bank/bed mid-section	Fully piped/culvert
Land tenure score	Reserve or Public open space	Road reserve / easement	Other public vested interest	Private/piped/culvert
Public amenity	Public thoroughfare, visual amenity and area ambience	Thoroughfare	Access but no thoroughfare	No public access
Maintenance (personnel, equipment access, scale of works)	Fully accessible	Easement access	Easement/Reserve, access through private property	Private ownership - constrained access/Culvert

Table 6: Tier 1 Summary of opportunities, objectives and design considerations.

Note: these sections are ordered in sequence downstream from the headwaters, not in order of priority.

(Grouped sections) Tier 1	General location	Rehabilitation opportunities/ Management objectives	Project design considerations
1 A05.1, A05.2, A05.3, A11	Dunn Park bounded by Dunn, Whidby and Broughton Streets	Opportunity exists to create a constructed ephemeral wetland as a vegetated bio-filter detention area designed to remove pollutants from stormwater and attenuate larger storm events in a modified detention area. Management objectives are: • reduce sediment, nutrient and other pollutant export, • improve visual and recreational amenity, • increase shading to limit weeds and algal growth, • erosion control through soft engineering, • reconnection of existing remnant bush patch to streamline revegetation, • increase terrestrial and aquatic habitat and biodiversity values, • stormwater and low flow detention control, • gross pollutant trapping at lower end (Broughton St).	The area offers a demonstration site for water sensitive urban design in a highly visible location. Install an ephemeral detention and bio-filter wetland for both channels. Ensure low flows are directed through bio-filters. Note; this will require the Bevan Street tributary flood flows to be detain more effectively at Bevan Street. (See Tier 2, Point 2 in Table 8) Improve connectivity and visual amenity regarding public access to the light industrial area as well as the High School. Utilise pathways to separate lawn grass from native revegetated areas. Improve public walkway alongside the channel between Whidby and Broughton Streets. Recover sufficient flat area for residents to be able to 'kick a ball' around. Protect the remnant native bush patch which currently is in moderate condition and representative of the original bush cover. Connect remnant bush to stream revegetation. Use block sedge plantings along water's edge and on fluvial terraces to reduce weed incursion and protect from erosion. Plant shade trees strategically alongside the creek and wetland Adequate visibility across the parkland should be maintained for security (i.e. medium height trees, ground cover and channel fringe species with less

(Grouped sections) Tier 1	General location	Rehabilitation opportunities/ Management objectives	Project design considerations
			emphasis on middle story shrubs). Install a sign with an artist's impression of the final outcome before the proposed works.
2 B06.1, B06.2, B07, B08	Adjacent to Barnesby Drive and Yakamia Primary School	Build on current Living Stream works through weed management and re-vegetation guided by the development of a holistic plan for these sections. Management objectives: • reduce bank slope of high eroding steep banks, • improve visual amenity, • erosion control and bed and bank stability through soft engineering, • improved connecting pathways, • removal of the eastern states swamp mahogany eucalypts using a staged approach, • reduce flow velocity of stormwater conveyance, • increase channel shading to improve water temperatures, • increase terrestrial and aquatic habitat and biodiversity values, • weed control, • gross pollutant trapping at lower end (North Road).	Produce a detailed landscape map of the whole precinct to promote aesthetic, community and environmental aspects and to guide future projects. High eroding steep banks occur in some sections (e.g. lower part of sections B07. These bank slopes need to be reduced for public safety reasons as well as remove a source of sediment. Use block sedge plantings along water's edge and on fluvial terraces to reduce weed incursion and protect from erosion. Use the bridges and walk paths on both sides to develop an exercise circuit with outdoor exercise equipment. Utilise pathways to separate lawn grass from native revegetated areas. Replace the crossing between Sections 6.1 and 6.2 with one that is more visually pleasing and with less interference with the channel cross-section. Install several rocky riffles to back flood head cut prone areas and reduce flow velocity (and hence bed incision) and increase aquatic habitat diversity. Implement a staged approach to the replacement of the eastern states swamp mahogany eucalypts with less invasive native trees and ground covers.

(Grouped sections) Tier 1	General location	Rehabilitation opportunities/ Management objectives	Project design considerations
3 C1, C2, C3, C4	Western end of Centennial Park Sporting Precinct.	Note: Plans for this area will need to incorporate the Centennial Park Sporting Precinct redevelopment plans. This area offers an opportunity for creating a complex urban waterway ecosystem involving a constructed wetland and bio-filter detention area that is also a public amenity. Management objectives: • gross pollutant trapping at top end to catch rubbish from North Road, • improve visual amenity, • reduce sediment, nutrient and other pollutant export, • dense planting to shade out weeds, • erosion control through soft engineering and adding sinuosity to channel, • reconnection of existing remnant bush patch to the streamline, • increase channel and wetland shading to improve water temperatures, • increase terrestrial and aquatic habitat and biodiversity values, • stormwater and low flow detention control.	Well-designed, a Living Stream can improve the visual amenity of this area. The area offers a demonstration site for water sensitive urban design in a highly visible location. Note: An environmental design for the Centennial Park Sporting Precinct has been drawn up by Syrinx Environmental to treat ground water and surface nutrient export from the sporting fields. It is not known what scope was in the brief to modify Yakamia Creek, however some concept plans have been submitted to the council. Details of their designs have not been available for viewing during the preparation of this document. There is room to add sinuosity into the channel to limit erosion and to develop a constructed wetland bio-filter and detention basin. Consider the use of block sedge plantings along water's edge and on fluvial terraces to reduce undercutting and bank erosion. The channel can be re-routed to enhance bio-filtration options. Ensure low flows are directed through bio-filters. The function of the two current culvert stormwater 'chokes' and the bunding needs to be reassessed in terms of future wetland and bio-filter detention. Section C1 contains a range of rocks, concrete and other structures that can be removed. The channel cross-section appears to be too small as evidenced by the extensive bank erosion on both sides of the channel. The wetland blocks to the west of sections C1 and C2 are owned by the City of Albany and it is recommended

(Grouped sections) Tier 1	General location	Rehabilitation opportunities/ Management objectives	Project design considerations
			these to be rezoned from residential to park. This would increase the land available for significant wetland features and improve bio-filtration efficiency. Assess what vegetation features need protection e.g. older wetland trees including their root zone. Ground water levels and acid sulphate soil assessment will be required during the planning phase. Public thoroughfare connections between Pioneer, North and Barker Roads can be enhanced. Utilise pathways to separate lawn grass from native revegetated areas and to link revegetated areas with the bike path to improve passive recreation. Consider installing a raised walkway through the wetland with viewing platforms and interpretive signage. Consider installing a sign with an artist's impression of the completed works to advertise the plan and to increase public awareness of Living Stream benefits. Liaise with Western Power regarding location of power poles. These should not dictate the design of drainage works appropriate to the area. Engage the local Noongar community in the design of the wetland precincts.
4 C9.1, C9.2	Centennial Park Athletics Precinct Sanford and North Roads	Note: Plans for this area will need to incorporate the Centennial Park Sporting Precinct redevelopment plans. The opportunity exists to restructure the channel form (cross-section and sinuosity), and improve the area ambience and visual amenity to complement	There is room to add sinuosity to the channel and to modify its cross-sectional shape to include fluvial terraces. Utilise block sedge plantings along the water's edge and on fluvial terraces to reduce undercutting and bank erosion. Bio-filtration of groundwater between the creek and the PCYC can be improved through

(Grouped sections) Tier 1	General location	Rehabilitation opportunities/ Management objectives	Project design considerations
		rehabilitation works across the road. Management objectives: • improve visual amenity, • tall tree planting to shade out weeds, • increase channel shading to improve water temperatures, • erosion control through soft engineering, • increase terrestrial and aquatic habitat and biodiversity values, • reduce flow velocity of stormwater conveyance, • gross pollutant trapping at lower end.	appropriate sedge and shrub planting. Maintain adequate foreshore buffer between channel and built infrastructure (at least 30 meters as initially requested by the Aboriginal Heritage Reference Group Aboriginal Corporation). The visual amenity of the creek can be greatly enhanced. Utilise pathways to separate lawn grass from native revegetated areas. Install a gross pollutant trap downstream of North and Sanford Roads to prevent rubbish from being washed down Yakamia Creek (PET bottles, snack wrappers and other rubbish have been observed and complained about, 3 kms downstream).
5 Ct3, Ct4	Centennial Park Central Precinct, Community parkland North Road and Lockyer Avenue	Note: Plans for this area will need to incorporate the Centennial Park Sporting Precinct redevelopment plans. An opportunity exists to develop a detailed landscape plan for the whole precinct within which these sections are a part. An opportunity exists to extend the existing riparian enhancement works as a shaded avenue along the eastern drainage line parallel to North Road. Management objectives: • improve visual amenity, • reduce sediment, nutrient and other pollutant export, • increase channel shading to improve water temperatures and limit weed growth, • erosion control through soft engineering, • reduce flow velocity of stormwater conveyance,	Consider a comprehensive landscape design approach to incorporate aesthetic, community and environmental aspects of the precinct for the two tributary branches and the lakes (sections Ct3, Ct4, Ct6, Ct7 and Ct8). There is room to add sinuosity to the channel and to modify its cross-sectional shape to include fluvial terraces. Utilise block sedge plantings along water's edge and on fluvial terraces to reduce erosion and increase bio-filtration. The visual amenity and passive recreation along the creek can be greatly enhanced. Provide an attractive pedestrian crossover between the two sections. Utilise pathways to separate lawn grass from native revegetated areas. The invasive aquatic weed Sagittaria has been found in

(Grouped sections) Tier 1	General location	Rehabilitation opportunities/ Management objectives	Project design considerations
		• increase terrestrial and aquatic habitat and biodiversity values, • stormwater conveyance.	these sections. It is a Weed of National Significance (WONS) and these sections need regular monitoring. Control of this weed is important to prevent it invading further downstream of North Road.
7 Ct 6, Ct7	Centennial Park Central Precinct, Community parkland The lakes and the recent rehabilitation site by Sanford Road	Note: Plans for this area will need to incorporate the Centennial Park Sporting Precinct redevelopment plans. The opportunity exists to build on the existing works through the creation of a landscape plan for the whole precinct within which these sections are a part. Opportunity exists to enhance the little dam at the very top of section Ct6 as a bio-filter prior to the water entering the lakes. Management objectives: • improve visual amenity, • reduce sediment, nutrient and other pollutant export, • increase channel shading to improve water temperatures, • bank protection through soft engineering, • increase terrestrial and aquatic habitat and biodiversity values, • reduce flow velocity of stormwater conveyance, • gross pollutant trapping at lower end.	Consider a landscape design approach to incorporate aesthetic, community and environmental aspects of the precinct for the two tributary branches and the lakes (sections Ct3, Ct4, Ct6, Ct7 and Ct8). All works should be part of a greater landscape design for the precinct.
6 E4, E5	Oyster Harbour foreshore reserve	No specific physical intervention is required here. Management objectives: • Protection from further disturbance due to	Limit maintenance access to the southern bank. Minimise disturbance to native vegetation during maintenance works. Note: The delta at the mouth of the creek supports a

(Grouped sections) Tier 1	General location	Rehabilitation opportunities/ Management objectives	Project design considerations
		drain maintenance. • Develop protocols for maintenance works.	range of wading bird species.

(Isolated sections) Tier 1	General location	Rehabilitation opportunities/ Management objectives	Project design considerations
8 Ct1	Downstream of the corner of Symers and Knight Streets, adjacent to the soccer fields.	Opportunity exists to restructure the channel form (cross-section and sinuosity), and improve the area ambience and visual amenity. Management objectives: • improve visual amenity, • increase channel shading to improve water temperatures, • erosion control through soft engineering, • increase terrestrial and aquatic habitat and biodiversity values, • reduce flow velocity of stormwater conveyance, • gross pollutant trapping at lower end.	The natural stream form and function should be allowed for in any landscape plan. Maintain adequate foreshore buffer between channel and built infrastructure (at least 10 metres here). Room can be made to add sinuosity to the channel and to modify its cross-sectional shape to include fluvial terraces. Utilise block sedge plantings along water's edge and on fluvial terraces to reduce erosion and add habitat and biodiversity values. Utilise pathways to separate lawn grass from native re-vegetated areas and provide bridge cross overs. Provision for interception and efficient removal of trash.
9 D1.2 (consider including D1.1 from Tier 2)	Adjacent to City of Albany Offices and RAAFA retirement village.	These two sections have been eroding with channel deepening due to a head cut that has travelled up to and exposed a coffee rock layer forming a 'water fall'. Before any stream rehabilitation works can be undertaken here, a full topographic survey needs to be undertaken.	Enhance ecological connectivity with adjacent artificial wetlands behind the City of Albany buildings. Provision of public parkland and thoroughfare from North Road and RAAFA Amity retirement village. Consider creating parkland and access easements in the case of sub-division of adjacent lands across the

(Isolated sections) Tier 1	General location	Rehabilitation opportunities/ Management objectives	Project design considerations
		This area offers an opportunity to connect future sub-divisions to the north with North Road, via public parkland with a strong environmental theme. Management objectives: • improve visual amenity, • reduce flow velocity of stormwater conveyance, • erosion control determined through survey, • increase terrestrial and aquatic habitat and biodiversity values, • weed control, • gross pollutant trapping just below the North Road culvert.	creek to the north. The unstable and steeply incised channel lends itself to demonstrating better channel cross-section design that accommodates natural stream features including diversity of habitat (designed fluvial terraces and increased sinuosity). Improved bed and bank stability and weed management may provide a template for Best Management Practices for downstream landholders and future system modifications, without detracting from the channels flood water conveyance capacity. Note that the proposed plan for the Range Road intersection opposite Sanford Road within the Yakamia/Lange Structure Plan implies that the road cuts across the bend of Yakamia Creek. Any further designing of the Range Road, North Road intersection should include a plan for rehabilitating this section of Yakamia Creek with a Living Stream emphasis. (See further notes in Tier 2 table). The proposed Range Road intersection ignores proper stream form and function in this area. A minimum foreshore buffer of not less than 10m wide from the top of both banks should allow for access to downstream sections. Note that the Aboriginal Heritage Reference Group Aboriginal Corporation have requested at least a 30 metre buffer.

Recommendations to OHCG for Tier 1 sites

The Barnesby Drive Living Stream project highlighted the fact urban Living Stream development deals with numerous and diverse community expectations to a greater extent than many rural river restoration projects,. This is reflected in the multiple roles that streams play in this environment. Environmental Problem solvers should recognise that the social aspects of waterways management are as important as the implementation of an on-ground environmental ideal. A Living Stream project is not simply about putting up a fence to limit stock (or people) access and re-vegetation of the riparian zone. It has to be integrated with the requirements of residential and industrial infrastructure. For this reason the OHCG will only ever be one of a number of stakeholders all with differing demands on the outcomes of foreshore project proposals.

One of the aims of this Living Stream Management Plan was to identify the next 2 – 5 sites for Living Stream projects. The opportunities assessment identified nine potential sites as listed in Table 6. The suggested priority sites at this stage are:

- Dunn Park (ncluding Bevan Street)
- Upper Barnesby Drive
- The western end of the Centennial Park Sporting Precinct
- Downstream of North/Sanford Road

For all parts of the target areas of the creek, key stakeholders are the City of Albany, the local Noongar community, Water Corporation, Department of Water, Department of Aboriginal Affairs, South Coast NRM, and the Health Department. Other stakeholders concerned with specific reaches of the creek are; residents, assorted sporting groups, other community interest and 'Friends of' groups, Centennial Park Sporting Precinct committee, businesses including land developers, Main Roads Department, Department of Planning, Fisheries WA and others. The following recommendations for OHCG outline project opportunities and engagement in this social context.

Some general recommendations for the OHCG

- Determine what proportion of the OHCG's time and effort can realistically be allocated to Yakamia Creek over a specific time frame, for example 2015 to 2025.
- Ensure that project officers have a mandate in their contracts to routinely liaise with stakeholders regarding project developments and needed resources along Yakamia Creek.
- Develop a support model for weed management along the creek, with SCNRM, Friends of Yakamia Creek, the Noongar community, Bushcarers and other relevant groups. The current model for funding NRM projects has the disadvantage of creating a competitive or isolated outlook amongst groups who often have common aims.
- Provide basic training for project officers in the area of Water Sensitive Urban Design (WSUD).
- Develop a framework (not parts of individual projects) to facilitate periodic monitoring of the environmental outcomes of riparian management projects after they have been completed. Often this aspect of environmental management is not factored into many plans and is soon displaced by other projects and neglected.
- Seek and support a local champion(s) who can be an advocate for better environmental management in the Yakamia Creek catchment.

Table 7: Recommendations to OHCG for Tier 1 sections

(Grouped sections) Tier 1	General location	Key stakeholders	Recommended project focus for the OHCG
1 A05.1, A05.2, A05.3, A11	Dunn Park bounded by Dunn, Whidby and Broughton Streets	City of Albany (CoA), residents, Water Corporation, Health Department, Noongar Community.	Liaise with the CoA regarding a constructed wetland/ bio-filter design to improve the water quality and social amenity of the park area. Consult with the local Noongar community regarding ideas and proposals for the area.
2 B06.1, B06.2, B07, B08	Adjacent Barnesby Drive and Yakamia Primary School	CoA, residents, Friends of Yakamia Creek, Yakamia Primary School, Noongar Community.	Consult with the Yakamia Primary School regarding educational opportunities for these sections of the creek. Work with the Friends of Yakamia Creek to incrementally replace the exotic eucalypts with less invasive native trees. Liaise with private landholders of the Tier 2 sections upstream (as far as Chester Pass Road) to control Sydney Wattles and other weed infestations along the creek. Consider projects to redesign and upgrade the pedestrian culvert crossings along these sections
3, 4, 5, 7 C1, C2, C3, C4, C09.1, C09.2, Ct3, Ct4, Ct 6, Ct7	Centennial Park Sporting Precinct.	CoA, Centennial Park Sporting Precinct Committee, Noongar Community	Consult with the City of Albany and the Centennial Park Sporting Precinct Committee to determine how the proposed nutrient bio-filtration design (designed by Syrinx Environmental and before council) fits in with a constructed wetland/ bio-filter function and maintenance. Future projects may involve modifications to the initial installation to improve ecological outcomes in the long term. Ongoing maintenance will be an important issue.
6 E4, E5	Oyster Harbour foreshore reserve		Be an advocate for the conservation of the foreshore areas at the mouth of Yakamia Creek to prevent further excavation and unnecessary damage to riparian vegetation. Develop specific protocols to govern sediment removal if this is needed to improve the drainage efficiency of the channel. Currently this natural asset is out of sight and out of mind (apart from UWA interest in water quality).

(Isolated sections) Tier 1	**General location**	**Key stakeholders**	Recommended project focus for the OHCG
8 Ct1	Downstream of the corner of Symers and Knight Streets, adjacent to the soccer fields.	CoA, Centennial Park Sporting Precinct Committee and the Agricultural Show committee.	Liaise with the CoA regarding appropriate channel and riparian design with improved nutrient and contaminant stripping capacity.
9 D1.2 (and D1.1 from Tier 2)	Adjacent City of Albany Offices and RAAFA retirement village.	CoA	Liaise with the CoA to provide sufficient (WSUD) riparian buffer width at the North Road intersection in the proposed Range Road intersection plans. Consult with the CoA to consider riparian and channel modifications to create a Living Stream floodway as the lead in for future concept plans for any proposed riparian corridor through the downstream sections. <u>Note</u> that this section offers one of the few opportunities for OHCG to be the principal project proponent in collaboration with the City of Albany.

Concept plans for selected Tier 1 targets

An environmental design for the Centennial Park Sporting Precinct has been drawn up by Syrinx Environmental to treat ground water and surface nutrient export from the sporting fields. It is not known what scope was in their brief to modify Yakamia Creek; however some concept plans have been submitted to the council. Details of their designs have not been available for viewing during the preparation of this document.

These concept plans for constructed wetlands on several Tier 1 targets are presented for consideration. Please note that they are conceptual only and for the purpose of examining possibilities. There are many considerations which were beyond the scope of this report and which require assessment before commencing a specific site design process. The Department of Water (WA) and Melbourne Water have excellent publications outlining design guidelines for constructed wetlands.

Constructed wetlands are vegetated water flow detention areas which are designed to remove fine particulate matter and dissolved pollutants from low flows with a high flow by-pass which comes into effect once the wetland has been filled to capacity. The effectiveness of constructed wetlands is dependent on reducing flow velocity and promoting biological transformations of pollutants by passing the flow through a series of pools and biofilms in vegetation bands. See Figure 16 for a schematic representation of a typical constructed wetland.

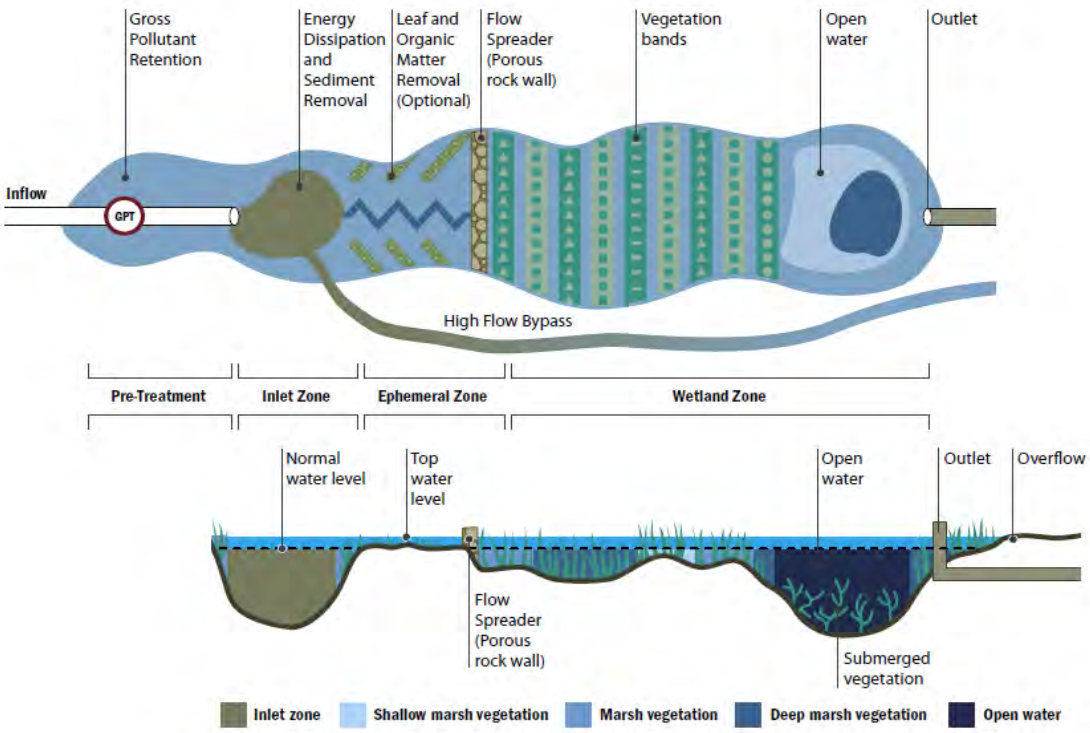

Figure 16: Schematic representation of a typical constructed wetland in plan view and longitudinal view. (from Melbourne Water (2005)1)

Other benefits of constructed wetlands are landscape amenity, and habitat creation. Connecting a constructed wetland to existing bushland vegetation will enhance both the bush land and the wetland. It should be noted that many Western Australian wetlands are ephemeral and dry out in

[1] "**Constructed Wetland System** Design Guidelines for Developers" Version 3 (2005) Melbourne Water.

summer. The issues of acid sulphate soils will need to be considered prior to the construction of any biofilter wetlands.

An observation on the limited success of various revegetation projects is the frequent skimping on the density of planting. It was noted on the Bannister Creek rehabilitation project that blocks of sedges were planted along the water's edge, forming mats of vegetation that were pinned in place. Although they were more expensive, they gave a better result[1]. Densely planting small sections is preferable to sparsely planting a larger area.

Costs for constructing wetlands vary depending on many factors. The Department of Water (in "Stormwater Management Manual"[2]) cite 2002 eastern states examples as ranging from approximately $500 000 to $700 000 per wetland hectare with earthworks and vegetation being the dominant costs. They also cite maintenance costs as approximately 2% of construction costs.

The **New WAter Ways** brochure[3] on the Liege Street Wetland gives their costs for both development and maintenance. This wetland is about one hectare within a four hectare site.

Development Costs

Conceptual design and construction/ revegetation specifications	$63,000
Construction [1]	$726,000
Planting and restoration activities [2]	$74,000
Total (ex GST)[3,4,5,6]	$863,000

1. Approximate figure, includes in-kind funding.
2. Includes supervision time but does not account for volunteer time (not tracked but significant).
3. Construction/revegetation costs only relate to wetland design and implementation and not landscape elements (e.g. signage, boardwalks, paths, seating, etc.).
4. Costs in 2004-05.
5. SRT, Water Corporation, City of Canning staff time for planning not quantified.
6. Costs relate to implementation of both the ~1ha wetland and the entire ~4ha site in which the wetland is located.

Maintenance Costs [1,2]

• 2005/2006	$30,200
• 2006/2007	$30,300
• 2007/2008	$20,200
• 2008/2009	$24,600
• 2009/2010	$24,100
• 2010/2011	$21,100

1. All figures are an approximation of costs which includes supervision time but does not account for volunteer time and excludes GST. Planning and management for staff at Swan River Trust, Water Corporation, and City of Canning have not been quantified
2. Costs relate to maintenance of both the ~1 ha wetland and the entire ~4ha site in which the wetland is located

[1] Per. com. Julie Roberts, CEO of South East Regional Centre for Urban Landcare.

[2] "Storm water Management Manual for Western Australia: Structural Controls" Department of Water (2004–2007), accessed from the internet 1/4/2014 at;
http://portal.water.wa.gov.au/portal/page/portal/WaterManagement/Storm water/Storm waterMgtManual

[3] New Water Ways case study Liege Street Wetland accessed from the internet on 1/4/2014
http://www.newwaterways.org.au/Resources/Case-studies-fact-sheets/WSUD-case-studies

Western End of Centennial Park Sporting Precinct –- Sections C1, C2, C3 & C4

This area offers an excellent opportunity for creating a complex urban waterways ecosystem involving constructed wetlands and a bio-filter detention area that is also a public amenity. Figure 17 shows a concept design for the area including the City of Albany owned land to the west of the current channel.

- The area offers a demonstration site for water sensitive urban design in a highly visible location.
- It increases the public amenity of the sporting precinct.
- It is within sight of the Barnesby Drive Living Stream works.
- The broad space available offers an excellent opportunity to create a complex riparian system incorporating the flood plain with the stream channel.

Note: Note: Plans for this area will need to incorporate the Centennial Park Sporting Precinct redevelopment plans.

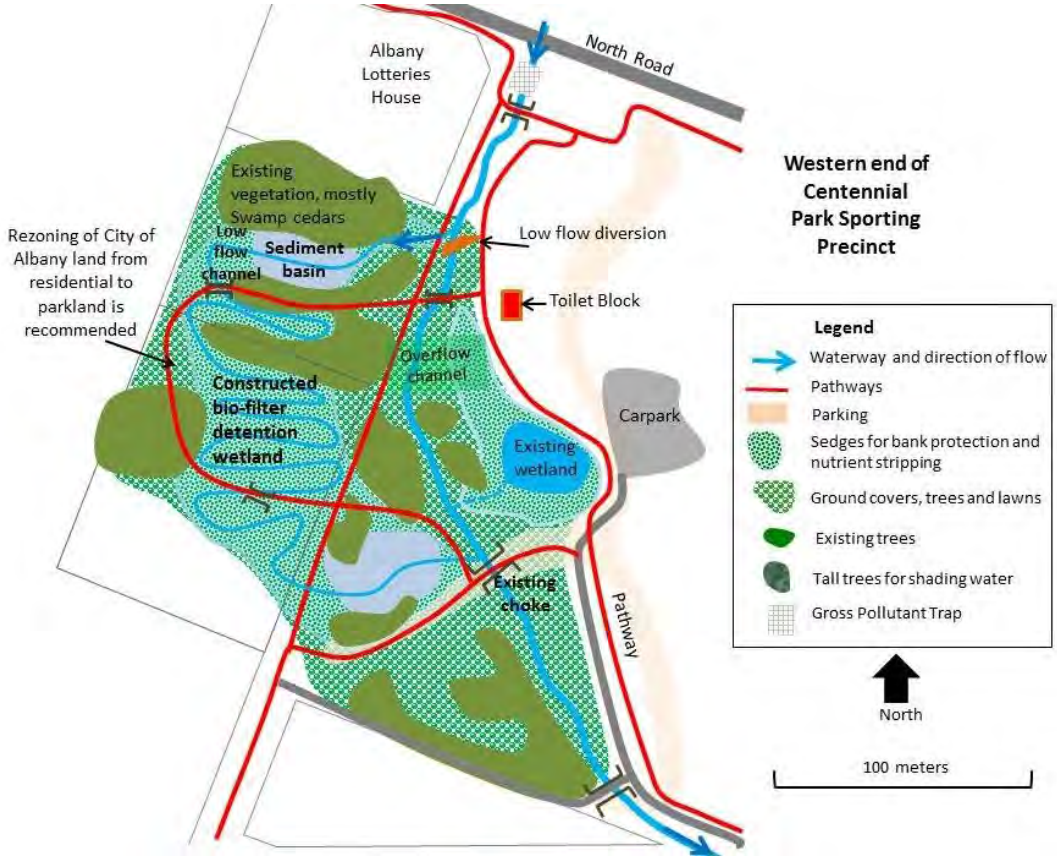

Figure 17: Concept design for constructed wetland and bio-filter detention area for the western end of Centennial Park Sporting Precinct.

There is room to add sinuosity into the channel to limit erosion and to develop a constructed wetland bio-filter and detention basin. The wetland properties to the west of sections C1 and C2 and owned by the City of Albany may require rezoning from residential to park. This would increase the land available for significant wetland features and improve bio-filtration efficiency. Drainage from the sporting grounds will also require bio-filtration before entering the channel.

It is also suggested that due consideration be given to the quality of surface and groundwater entering the creek system from the southern and western sides of the creek, opposite the playing fields. Discussions with the City suggest that re-routing the main channel to the southern side of the area would provide more space for a constructed wetland.

Public thoroughfare connections between Pioneer, North and Barker Roads can be enhanced with linkages through the revegetated areas and the existing bike paths to improve passive recreation. Community awareness of environmental issues can be addressed with a raised walkway through the wetland, viewing platforms and interpretive signage. The local Noongar community should be engaged in the implementation of the wetland precinct and interpretive signage.

Dunn Park Concept Plan - A05.1, A05.2, A05.3, A11

An opportunity exists to value add to the existing detention pond at Dunn park by transforming it into a constructed ephemeral wetland. A vegetated bio-filter detention area can be designed to remove pollutants from stormwater and attenuate larger storm events in the existing detention area. The area offers a demonstration site for water sensitive urban design in a highly visible location. Figure 18 shows a concept design for the area.

Two stream sources meet at the lower end of the park. The catchments for both of these channels include paved industrial areas which can produce rapid surface storm water runoff events. The Bevan Street tributary flood flows will need to be detained more effectively than the current detention basin may allow. The Bevan Street area (Sections A07, A08 and A09) could be redeveloped into another ephemeral wetland and bio-filter detention area to 'clean' the water flowing from the upstream industrial area and detain flood flows more efficiently. This is discussed further under Tier 2 sites.

Figure 18: Concept design for constructed ephemeral wetland and bio-filter detention area for Dunn Park.

The remnant native bush patch in the centre of Dunn Park is currently in moderate condition and is representative of the original bush cover. There are threats to its integrity due to the abutting grassed areas. The remnant patch can be protected by linking it with revegetation around the channel and wetland. Block sedge plantings along the water's edge and on fluvial terraces are recommended as they establish quickly, provide a sufficient density to reduce weed incursion and protect the bank from erosion.

The current detention basin in Dunn Park tends to remain soggy for much of the year and has reduced the open space area for residents to 'kick a ball around'. It is recommended that sufficient flat area be recovered in the design process.

The redesigned basin area is at the confluence of section A5.3 (the current detention basin) with section A11 that receives flows from the Bevan Street stormwater sump. The primary design issue is ensuring that high storm discharge from both sources can be adequately accommodated.

Centennial Park Athletics Precinct - C09.1, C09.2

It is suggested that the City plans to redesign this area should take the opportunity to restructure the channel form (cross-section and sinuosity as well as improve the area ambience and visual amenity to complement rehabilitation works across Sanford Road. Figure 19 is a concept design for the area that builds upon the design prepared for the City of Albany and was illustrated in the Community Update Winter 2013[1]. It indicates a new carpark below the creek which is supported however it is recommended that an adequate foreshore buffer between the carpark and the creek be maintained. It is also recommended that bio-retention systems be incorporated in the carpark design.

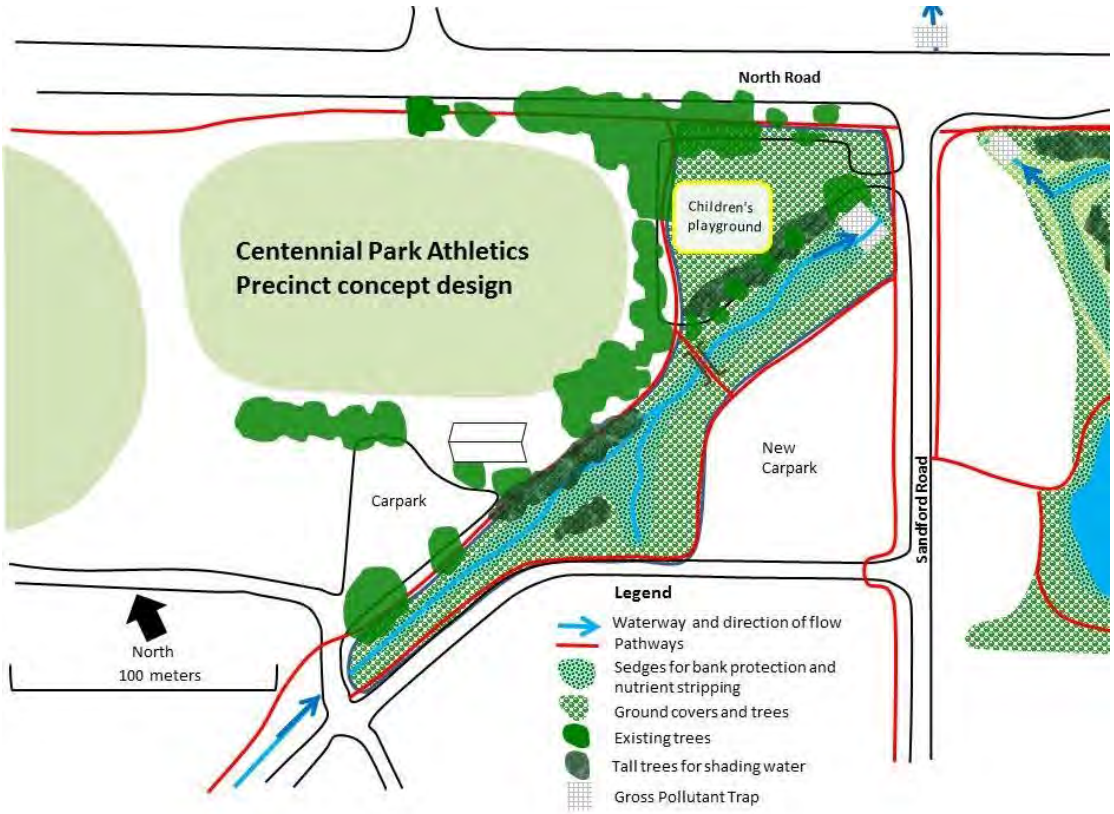

Figure 19: Concept design for Living Stream rehabilitation for sections C08 and C09 of Yakamia Creek

There is room to add sinuosity to the channel and to modify its cross-sectional shape to include fluvial terraces. Utilise block sedge plantings along water's edge and on fluvial terraces to reduce undercutting and bank erosion. Bio-filtration of groundwater between the creek and the PCYC can be improved through appropriate sedge and shrub planting.

PET bottles, snack wrappers and other rubbish have been observed and complained about some 3 kilometers downstream. An easily serviced Gross Pollutant Traps (GPT) below North Road is

[1] City of Albany Community Update Winter 2013 Centennial Park Sporting Precinct.

recommended to prevent rubbish being washed into the lower reaches and eventually Oyster Harbour.

Centennial Park Central Precinct, Community parkland - Ct3, Ct4 and Ct 6, Ct7

An opportunity exists to extend the landscape plan for the whole precinct to incorporate the existing riparian enhancement works as a shaded avenue along the eastern drainage line parallel to North Road. The landscape design should incorporate aesthetic, community and environmental aspects of the precinct for the two tributary branches and the lakes. Figure 20 shows a concept design for the area which is similar to the concept design prepared for the City of Albany as illustrated in the Community Update Winter 2013[1].

There is room to add sinuosity to the channels and to modify their cross-sectional shape to include fluvial benches. Block sedge plantings within the channel and along water's edge and on fluvial terraces reduce erosion, increase bio-filtration and reduce weeds. The two small swales entering the eastern branch would, ideally, be incorporated into the bio-filtration design.

An opportunity exists to enhance the small dam at the very top of section Ct6 to treat water from the light industrial and shopping areas, before it enters the lakes. This can also act as a bio-filter. Provision for interception and efficient removal of trash and sediment (pre-bay) before entry into the lake is also recommended.

Figure 20: Concept design for Living Stream rehabilitation for sections Ct3, Ct4, Ct6, Ct7 and Ct8 of two tributaries entering Yakamia Creek

[1] City of Albany Community Update Winter 2013 Centennial Park Sporting Precinct.

Centennial Park Soccer Precinct – Ct1

This short linear drain is situated to provide an opportunity to restructure the channel form (cross-section and sinuosity), and improve the area ambience and visual amenity. Any landscape planning for this area should allow for some improved natural stream form and function. Figure 21 shows a concept design for the area.

Room can be made to add slight sinuosity to the channel and to modify its cross-sectional shape to include fluvial terraces. The utilization of block sedge plantings along water's edge and on fluvial terraces can reduce erosion and add habitat and biodiversity values. Pathways can be used to separate lawn grass from native revegetated areas and provide access to bridge cross overs.

It is suggested that since this section is bounded upstream and downstream by piped sections, some provision needs to be made to facilitate the periodic removal of sediment and trash.

Figure 21: Concept design for Living Stream rehabilitation for section Ct1 of the Knight Street tributary to Yakamia Creek

Table 8: Tier 2 Summary of opportunities, objectives and design considerations.

Note: these sections are ordered in sequence downstream from the headwaters, not in order of priority. It is suggested it would be premature to design Living Stream projects for Tier 2 sections downstream of North Road until landholder agreement to basic concept plans is secured or sufficient riparian foreshore has been excised through the subdivision process.

(Grouped sections) Tier 2	General location	Rehabilitation opportunities/ Management objectives	Project design considerations
1 A1.1, A1.2	Urban drain upstream of Anson Road	A shallow linear drain runs through private property at a boundary and currently serves light industrial blocks including the green waste facility. Possibilities exist to detain and retain storm discharge, but particularly to improve bio-filtration capacity for nutrient and contaminant stripping. Management objectives are: • reduce sediment, nutrient and other pollutant export, • stormwater and low flow detention control.	Further development of the land should require installation of stormwater retention and infiltration systems on the properties and adjacent to the drain.
2 A7, A8, A9	Bevan Street to existing stormwater detention basin	A short section of open stream line connects the light industrial areas via Bevan Street, to an existing fenced detention basin. The opportunity exists to create an ephemeral constructed wetland detention basin and bio-filter within the road reserve and adjacent Lot 109 Whidby Road and the existing fenced detention basin. Part of this section is a deep open ditch and part is piped underground. Management objectives are: • reduce sediment, nutrient and other pollutant export, • stormwater and low flow detention control, • improve visual amenity,	The area has a backyard, out-of-sight-out-of -mind appearance (i.e. unsightly), but it is a public thoroughfare. Rehabilitation would improve the interface between residential land and business premises and improve land values. Procuring Lot 109 Whidby Street and the road reserve would provide a larger connected area for the design of an ephemeral constructed wetland and enhance its storm water capacity and bio-filtration function. Any re-vegetation design should take into account visibility as an important consideration for area security. Currently water quality, particularly pathogen and

(Grouped sections) Tier 2	General location	Rehabilitation opportunities/ Management objectives	Project design considerations
		• increase terrestrial and aquatic habitat and biodiversity values, • improved connecting pathways.	petrochemical levels are a concern. Detaining and bio-filtering more stormwater in this area would help relieve pressure on the bio-filter and detention area at Dunn Park. Involve the local residents and the Noongar community in the planning phase to improve a sense of ownership of the area.
3 B2, B3, B4, B5	Between Chester Pass Road and Barnesby Drive	This group of sections links the rehabilitation works downstream along Barnesby Road with Chester pass Road and therefore offers an opportunity to improve connectivity and consistency of management. Management objectives are: • stormwater conveyance, • reduce sediment, nutrient and other pollutant export, • improve visual amenity, • increase terrestrial and aquatic habitat and biodiversity values, • erosion control and bed and bank stability through soft engineering, • weed control.	Improving stream connectivity by 'defragmenting' these sections is an important design consideration. Maximise the channel foreshore riparian buffer width in the design. (at least 30 metres as requested by the Aboriginal Heritage Reference Group Aboriginal Corporation) Utilise block sedge plantings along water's edge and on fluvial terraces to reduce bank erosion. Improved public thoroughfare would strengthen the connection to the CBD, improve area ambience and therefore land values. Provision of a walkway and bicycle path. The adjacent bush is Jarrah, Marri, Sheoak laterite forest with parts in moderate condition. Ensure connection of retained remnant vegetation to foreshore riparian buffer.
4 C5, C6	Upstream of the Albany Leisure and Aquatic Centre at the	The current bank armoring is slowly collapsing in places. The eventual replacement of the current drain structure with Living Stream meandering channel and modified	Any significant environmental rehabilitation along these sections would require replacement of the straight armoured ditch with a slightly meandering

(Grouped sections) Tier 2	General location	Rehabilitation opportunities/ Management objectives	Project design considerations
	end of Barker Road and adjacent to the western parking area	cross-section needs to be included in the current planning of the area. Management objectives are: • stormwater conveyance, • improve visual amenity, • increase terrestrial and aquatic habitat and biodiversity values, • erosion control and bed and bank stability through soft engineering, • reduce flow velocity of stormwater conveyance by adding sinuosity to channel.	channel and modified cross sectional shape to include fluvial terraces. Utilise block sedge plantings along water's edge and on fluvial terraces to reduce undercutting and bank erosion. There is a short trapezoidal drain entering on the western bank that comes from Albany Highway via Pioneer Road. This was restructured in 2014 pending the construction of units on the adjacent private land. Maintain adequate foreshore buffer between channel and built infrastructure (at least 30 metres as requested by the Aboriginal Heritage Reference Group Aboriginal Corporation).
5 D2.1 to D5.9	North Road to Lower King Road	It is suggested that OHCG involvement in the foreshore management of these lower reaches would be premature and limited with respect to initiating any substantial on-ground works. The principle management need here is to achieve consensus between landholders and the City regarding the future of the waterway. In that respect it is suggested that the OHCG should not consider committing to Living Stream projects at this time. However, support for more consistent floodway maintenance actions would likely be accepted by a number of residents. The general recommendations are that the OHCG;	Living Stream project activity will need to be guided by the City of Albany development plans that unfold over the coming decade as defined in the Yakamia/Lange Structure Plan. [1] Three flood zones may be designated according to the 100 year ARI boundary. (See Figure 24) These sections form the longest reach of Yakamia Creek with the greatest potential for a continuous, integrated and multi-functional riparian corridor. Current landholder expectations limit Living Stream

[1] City of Albany Policy (2014) Yakamia/Lange Structure Plan

(Grouped sections) Tier 2	General location	Rehabilitation opportunities/ Management objectives	Project design considerations
		• Be an active advocate for the Yakamia/ Lange riparian corridor plan. • Promote better riparian management practices through information and media products. • Support weed management projects. A more detailed discussion can be found under the heading 'Summary of General recommendations to OHCG for Tier 2 sections downstream of North Road.' and 'Best and better foreshore management practices for the lower Yakamia Creek.' Management objectives are: • develop an ecological and hydrological detailed plan for the whole length, • constrain development within the foreshore riparian zone defined by CoA Yakamia/Lange Structure Plan[1], • increase terrestrial and aquatic habitat and biodiversity values, • weed control • erosion control and bed and bank stability through soft engineering, • reduce flow velocity of stormwater conveyance by adding sinuosity to channel.	development along these sections to weed management and localised bank stabilization works. Environmental considerations conflict with landholder expectations for land use and for excavating a large enough channel to remove the risk of flooding. The flood plain should be retained as a floodplain with no substantial infrastructure development permitted. A detailed model of the floodplain, identifying and incorporating ecological as well as hydrological processes is required. Current concept models are an insufficient foundation on which to build the desired holistic plan for best management of Yakamia Creek between North Road and Oyster Harbour. Such a plan would ideally be supported by obtaining a Digital Elevation Model (DEM) of the entire floodway, to an accuracy of at most +/- 10 cm, to clearly delineate the many drainage features. The case study of Bannister Creek shows what can be achieved when retrofitting a dug drain into a Living Stream in similar sandy soils.

[1] City of Albany Policy (2014) Yakamia/Lange Structure Plan

(Grouped sections) Tier 2	General location	Rehabilitation opportunities/ Management objectives	Project design considerations
6 E1, E2, E3	Between Lower King Road and the Oyster Harbour foreshore reserve	Opportunities for environmental rehabilitation are uncertain at this stage. The discussion under the heading 'Summary of General recommendations to OHCG for Tier 2 sections downstream of North Road.' and 'Best and better foreshore management practices for the lower Yakamia Creek' It is suggested that OHCG involvement in the foreshore management of these lower reaches would be premature and limited with respect to any substantial on-ground works. The preliminary management is to achieve consensus between landholders and the City regarding the future of the waterway. In that respect it is suggested that the OHCG should not consider committing to Living Stream projects at this time. However, support for more consistent floodway maintenance actions would likely be accepted by a number of residents. The general recommendations are that the OHCG; • Be an active advocate for the extension of the Yakamia/ Lange riparian corridor concept to link with Oyster Harbour. • Promote better riparian management practices through information and media products. • Support weed management projects. Management objectives are: • develop an ecological and hydrological concept plan for the whole length of these sections, • increase terrestrial and aquatic habitat and biodiversity values,	Consultation with the landholder to determine how the creek is functioning, is a prerequisite. Woody weeds are a significant issue, but appear to be serving a channel stabilization role in some sections.

(Grouped sections) Tier 2	General location	Rehabilitation opportunities/ Management objectives	Project design considerations
		• weed control, with replacement by comparable native plant species, • erosion control and bed and bank stability through soft engineering where appropriate, • Accommodate the natural tendency of the channel to adopt a sinuous form.	
7 Zone F	Tributary flowing downstream from Callistemon View (0.9 Km)	An opportunity exists to ensure an adequate foreshore riparian buffer zone is incorporated in the development of the area. This should include the damp scrubland of the valley floor and elements of the fringing woodland. See the discussion under the heading 'Summary of General recommendations to OHCG for Tier 2 sections downstream of North Road.' and 'Best and better foreshore management practices for the lower Yakamia Creek' It is suggested that OHCG involvement in the foreshore management of these lower reaches would be premature and limited with respect to on-ground works. The preliminary management is to achieve consensus between landholders and the City regarding the future of the waterway. In that respect it is suggested that the OHCG should not consider committing to Living Stream projects at this time. However, support for more consistent floodway maintenance actions would likely be	Until a detailed sub-division plan has been decided, project activity in these areas is limited to landholder engagement to undertake weed control. Nevertheless, pre-emptive weed management action is a critical need to ensure future developments can protect and maintain existing vegetation values. Later, specific Living Stream projects will be dependent on the recommendations of the by CoA Yakamia/Lange Structure Plan[1].

[1] City of Albany Policy (2014) Yakamia/Lange Structure Plan

(Grouped sections) Tier 2	General location	Rehabilitation opportunities/ Management objectives	Project design considerations
		accepted by a number of residents. The general recommendations are that the OHCG; • Support weed management projects. • Be an active advocate for the Yakamia/ Lange riparian corridor plan. • Promote better riparian management practices through information and media products. Management objectives are: • give the creek a name to establish its identity and ecological place in the community, • develop an ecological and hydrological detailed plan for the whole length, • constrain development within the foreshore riparian zone defined by CoA Yakamia/Lange Structure Plan[1], • increase terrestrial and aquatic habitat and biodiversity values, • weed control • erosion control and bed and bank stability through soft engineering, • reduce flow velocity of stormwater conveyance by adding sinuosity to channel.	

[1] City of Albany Policy (2014) Yakamia/Lange Structure Plan

(Grouped sections) Tier 2	General location	Rehabilitation opportunities/ Management objectives	Project design considerations
8 Zone G	Lange tributary, between Mercer, Catalina and Mason Roads (2.7 Km)	The opportunity exists to ensure an adequate foreshore riparian buffer zone is incorporated in the development of the area. This is to include the damp scrubland of the valley floor and elements of the fringing woodland. See the discussion under the heading 'Summary of General recommendations to OHCG for Tier 2 sections downstream of North Road.' and 'Best and better foreshore management practices for the lower Yakamia Creek' It is suggested that OHCG involvement in the foreshore management of these lower reaches would be premature and limited with respect to substantial on-ground works. The preliminary management is to achieve consensus between landholders and the City regarding the future of the waterway. In that respect it is suggested that the OHCG should not consider committing to substantial Living Stream projects at this time. However, support for more consistent floodway maintenance actions would likely be accepted by a number of residents. The general recommendations are that the OHCG; • Support weed management projects. • Be an active advocate for the Yakamia/ Lange riparian corridor plan. • Promote better riparian management practices	Until a detailed sub-division plan has been decided, project activity in these areas is limited to landholder engagement to undertake weed control. Later, specific Living Stream projects will be dependent on the recommendations of the by CoA Yakamia/Lange Structure Plan[1].

[1] City of Albany Policy (2014) Yakamia/Lange Structure Plan

(Grouped sections) Tier 2	General location	Rehabilitation opportunities/ Management objectives	Project design considerations
		through information and media products. Management objectives are: • give the creek a name to establish its identity and ecological place in the community, • develop an ecological and hydrological detailed plan for the whole length, • constrain development within the foreshore riparian zone defined by CoA Yakamia/Lange Structure Plan, • increase terrestrial and aquatic habitat and biodiversity values, • weed control • erosion control and bed and bank stability through soft engineering, • reduce flow velocity of stormwater conveyance by adding sinuosity to channel.	

Tier 2 (Isolated sections)	General location	Rehabilitation opportunities/ Management objectives	Project design considerations
9 C8	Immediately downstream of the Albany Leisure and Aquatic Centre	This section has been channelised and armoured; however future planning should consider creating a more natural transitional zone into the Living Stream rehabilitation proposed for the following two downstream sections. Management objectives are:	Any significant environmental rehabilitation along these sections would require replacement of the straight armoured ditch with a slightly meandering channel and modified cross sectional shape to include fluvial terraces. Utilise block sedge plantings along water's edge and on fluvial terraces to reduce undercutting and bank erosion.

Tier 2 (Isolated sections)	General location	Rehabilitation opportunities/ Management objectives	Project design considerations
		• stormwater conveyance, • improve visual amenity, • increase terrestrial and aquatic habitat and biodiversity values, • erosion control and bed and bank stability through soft engineering, • reduce flow velocity of stormwater conveyance by adding sinuosity to channel.	Maintain adequate foreshore buffer between channel and built infrastructure (at least 30 metres as requested by the Aboriginal Heritage Reference Group Aboriginal Corporation).
10 Ct 5	At western boundary of the Sanford Road football ground	There is room for improved bed and bank stabilization without compromising the drainage function. Management objectives are: • stormwater conveyance, • improve visual amenity, • increase terrestrial and aquatic habitat and biodiversity values, • erosion control and bed and bank stability through soft engineering, • reduce flow velocity of stormwater conveyance by adding sinuosity to channel.	A 'filter' at the lower end of this section would serve to improve water quality and intercept rubbish and sediment before it can enter the ornamental lakes .It should be designed to easily facilitate removal of accumulated material. There is little room to add sinuosity to the channel, but there is some scope to modify its cross-sectional shape to include fluvial terraces. The current flows are tending to form these at present. Utilise block sedge plantings along water's edge and on fluvial terraces to reduce erosion and increase bio-filtration.

11 D1.1	Immediately downstream of North Road and adjacent to the Water Corporation Sewerage pump station	This section is constrained for space, nevertheless it acts to connect the upper catchment to a broadening riparian area downstream. The comments for Section D1.2 in 'Table 6: Tier 1 Summary of opportunities, objectives and design considerations. are applicable here. Management objectives: • improve visual amenity, • reduce flow velocity of stormwater conveyance, • erosion control determined through survey, • increase terrestrial and aquatic habitat and biodiversity values, • weed control, • gross pollutant trapping just below the North Road culvert.	The current channel is highly incised with steep (potentially dangerous) banks. Head-cutting proceeded upstream after excavation and is now limited by an exposed lateritic shelf that has created a waterfall approximately 1.5 meters high. This feature may lend itself to enhancement if the downstream section is developed as an environmental park and better pedestrian access is provided. Proposed road works to connect North Road to the Lange urban development should allow for a sufficient vegetated buffer (> 10 m either side) along this short section to ensure that access to the sections downstream is not compromised. Adequate access will be important for future public amenity and maintenance of the lower reaches of the creek. Note that the Aboriginal Heritage Reference Group Aboriginal Corporation have requested at least a 30 metre buffer.

Summary of General recommendations to OHCG for Tier 2 sections downstream of North Road.

OHCG involvement in the foreshore management of these lower reaches is currently limited with respect to on-ground works. The principle management need here is to achieve consensus between landholders and the City regarding the future of the waterway. In that respect it is suggested that the OHCG should not consider committing to Living Stream projects at this time. However, support for more consistent floodway maintenance actions would likely be accepted by a number of residents. The general recommendations are therefore that the OHCG;

- Be an active advocate for the Yakamia/ Lange riparian corridor plan.
- Promote better riparian management practices and protection through information and media products.
- Support weed management projects.

Best and better foreshore management practices for the lower Yakamia Creek

The sections of Yakamia Creek between North Road and the Lower King Road have been rated as Tier 2 in terms of constraints on Living Stream development. The long-standing controversy about who should maintain the modified channel between North Road and Lower King Road and the resulting inaction, has promoted an inconsistent approach to both floodway improvement and maintenance. The continued controversy is the overarching constraint along these lower sections. It has also hindered the implementation of best management practices and thwarted attempts to create a detailed foreshore management plan that would be acceptable to landholders as well as the City of Albany.

The City of Albany's Yakamia/Lange Structure Plan[1] has an ultimate vision for the area that includes protection of the foreshore areas adjacent to waterways that feed into Oyster Harbour. The overarching objective of the plan is the creation of a broad, connected riparian corridor for the creek system between North Road and Martin Road including the two western tributaries (See Figure 22). This buffer along the main channel encompasses the flood prone areas and wetlands.

The allocation of land for the foreshore reserve will be a requirement of subdivision and future urban development. This is likely to occur gradually over a long period of time if the riparian zone is not to be resumed by the City. For this reason there are no reliable short-term opportunities to implement a holistic foreshore plan. Nevertheless, a detailed pre-emptive plan can be developed and this should constrain and steer future development in these flood plain areas. Thus best management practice (BMP) should be defined in terms of a holistic reconstruction of the floodway along the 6.4 Kilometer reach between North Road and Oyster Harbour.

It is beyond the scope of the Living Stream management plan to present a detailed riparian corridor design with sufficient detail to support the type of micro-management of the waterway needed to achieve the desired environmental outcomes. However, suggestions for what key elements should be covered in the working plan are presented.

The riparian area described in the Yakamia/Lange Structure Plan was based on the known flood extent and associated ecological values of the area. It represents an optimum design balancing the need for urban expansion with protection of water assets. The text boxes in Figure 22 suggests some interim management objectives. Since these actions concern private land holdings, ongoing community consultation will be essential to promote the concept plan.

[1] City of Albany Policy (2014) Yakamia/Lange Structure Plan

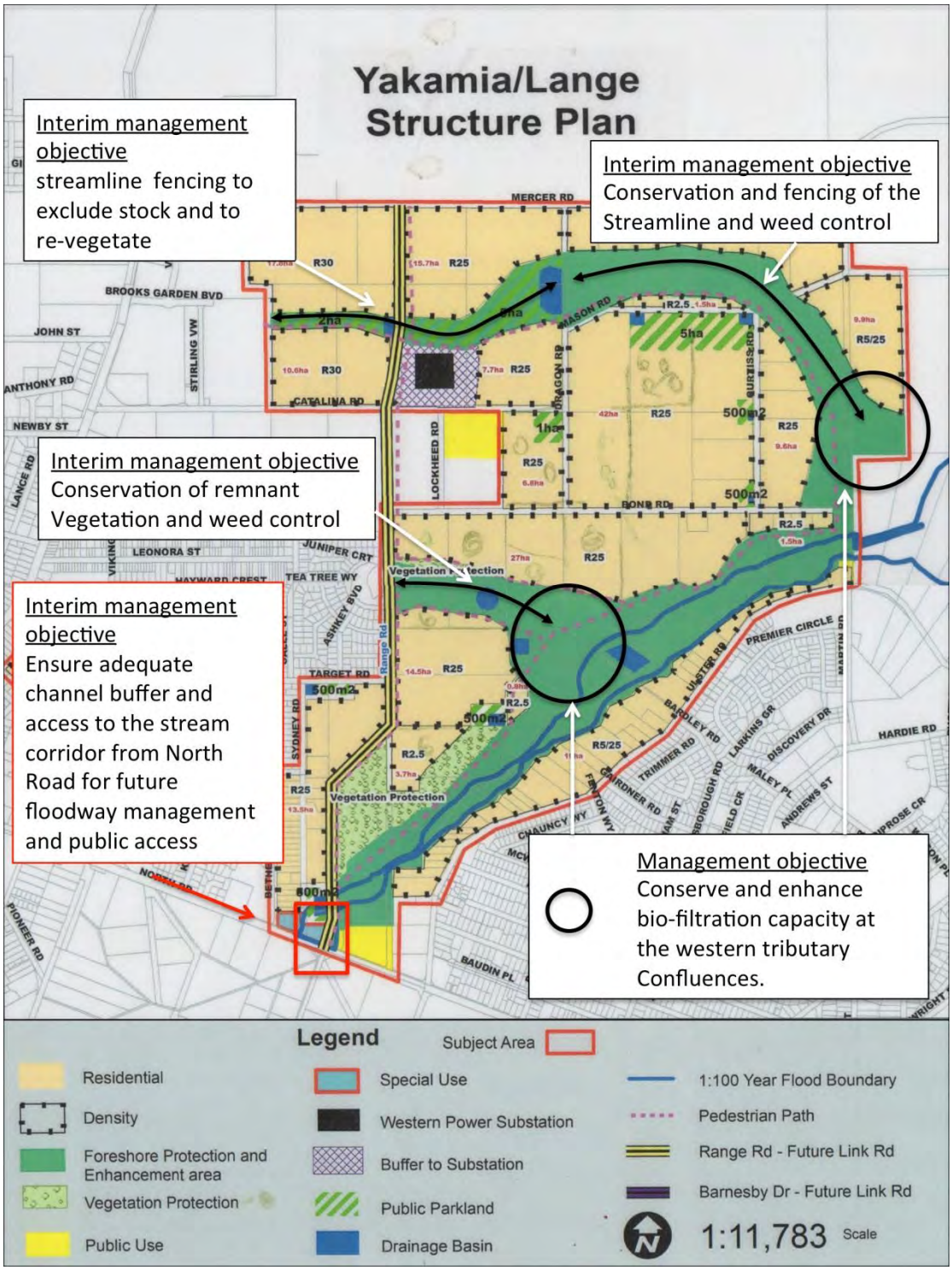

Figure 22: Yakamia / Lange Structure Plan with added interim management objectives in text boxes.

It is also recommended that more detail be obtained regarding the confluences of the western tributaries (to be named) for the purpose of determining existing and potential bio-filtration function in the waterways. The circles areas in Figure 22 are critical surface and subsurface water treatment sites.

Interim better management practices are suggested for the maintenance of the existing floodway of the creek. These can be promoted to landholders and are also applicable to ongoing foreshore management. These practices are discussed as principles and assertions in the following sections.

Channel and foreshore management practices

It may seem obvious, but floodplains are called floodplains for that simple reason.

In the effort to turn floodplains into something else landholders and local government agencies often find themselves fighting an age old battle with nature that is usually expensive, time consuming and often counter-productive. Sometimes works are of marginal benefit to the wider community though important to individual landholders or specific vested interests.

Figure 23: Extent of the 2005 flood. (Photo courtesy of Wilhelm Ficko).

The lower reaches of Yakamia Creek include broad floodplain and wetland zones where sediment is naturally deposited from turbid storm water. These reaches have a shallow gradient and flood waters are able to spread out (Figure 23).

Infrastructure (fences, sheds, buildings, tracks, crossings) built on the floodplain will always incur some risk of flood damage.

Since the Yakamia/Lange Structure Plan[1] is aimed at securing a riparian corridor through the sub-division process this will mean that many properties that currently span the floodplain will need dividing. Figure 24 below shows the approximate extent of 1 in 100 year flood levels. Three relatively distinct stream reaches based on flood extent, can be seen. While flooding may be of some inconvenience in the upper reach, it is of greater concern to owners of small properties in the middle reach and the larger properties along the lower reach.

[1] City of Albany Policy (2014) Yakamia/Lange Structure Plan

Figure 24: Distinct 1 in 100 year flood reaches along the middle to lower Yakamia Creek

The Yakamia/ Lange Structure Plan largely concerns the upper and middle reaches shown in Figure 24 and the proposed corridor is relatively confined. However, an adequate corridor along the lower reach that allows the system to act as a natural floodplain, is considered problematic due to the natural floodplain width. One compromise may be to direct and confine floodwaters towards the less developed northern side of the floodplain by enhancing detention and retention of water in those areas. These works would preferably be in the form of constructed wetlands providing bio-filtration of urban stormwater runoff and maintenance of fauna and flora habitat.

Landholders have argued that the City of Albany should be responsible to create and maintain a much larger channel. The claim that the City (i.e. rate payers) should bear the burden because the Town and Shire constructed the drain in the first place (1960) and that urbanization has subsequently increased catchment discharge, is only based on the premise that floodplains serve no useful purpose and should be dried out.

There is no guarantee that enlarging the main channel will achieve the desired result of 'drying out' the floodplain, given the hydrologic and geomorphologic characteristics of the area. Nevertheless from a Living Stream perspective, an enlarged channel may be hydraulically advantageous, given ongoing land development in the catchment. Such modifications should be based on reinstating appropriate natural stream form. In that case channel maintenance would be reduced to vegetation management within the floodway and floodplain areas. These assertions must be tested by hydrological modeling rather than by guesswork since the bed gradient is slight along lower reaches of the creek the (approximately 1 metre fall per Kilometre).

Better management practice

Plan and design infrastructure to cope with the inevitable extreme flood event

Detention basins can act like constricted floodplains while alleviating the impact of flooding further afield. They should also be allowed to serve multiple functions wherever possible. For example as vegetative bio-filters to improve water quality, create of bird and animal habitat, protect of remnant bush areas and improve social amenity of the area.

Figure 25: Sediment deposition in Yakamia Creek showing natural channel bank reconfiguration. Photo taken November 2014.

Sediment deposited from frequent moderate sized floods acts to fill in over widened or deepened channels (Figure 25) and the channel is generally reshaped to suit the annual pattern of flood discharge. Straightening and continual excavation of the channel generates an ongoing maintenance war. Over narrowing of the channel leads to increased bed and bank erosion as flows speed up and act to enlarge the cross-sectional area by scouring and undermining banks (Figure 26).

Best management practice

Channel dimensions (cross-sectional area and shape) should be determined on the basis of the hydrology of the catchment and the specific hydraulic conditions for each stream reach.

Figure 26: Neridup Creek near Esperance showing lateral enlargement of the creek channel as a consequence of the absence of stabilizing bank vegetation. Photo by Steve Janicke

Large floods created flood terraces or benches along this channel. Although these are a natural feature of many rivers and streams, removing vegetation accelerates the process considerably. If stabilised with vegetation the naturally enlarged areas can resist further erosion during subsequent floods. Aggressive excavation of the channel also destabilises the friable sandy soil of the bed and banks and sets the scene for further erosion.

A channel enlarged above its natural form may mitigate flooding up to a point, but is not likely to prevent it occurring in low lying areas during the occasional, but inevitable extreme storm events.

Levee banks retain flood waters in the dominant channel, they also retain sediment raising the bed level and decreasing the drainage efficiency of the channel and increasing the risk of flood waters breaching the banks.

Best management practice

Floodway vegetation is managed without unnecessarily disturbing the bed and bank soils.

Figure 27: Yakamia Creek rebuilding channel sinuosity. Photo taken November 2014.

Stream flows will act on a straightened channel to rebuild sinuosity (curvature) and this is characteristic of a more stable channel form (Figure 27).

Armoring the bed and banks may give some longevity to the drain, but poor armoring will eventually be damaged and can aggravate bed and bank erosion.

Better management practice

Where there are signs that the flow is tending to create bends in a channel these should be allowed to form and not be tampered with. Some stabilization of the steeper outside bends may be necessary and the bend can be controlled by removing part of the point bar if excess sedimentation is a problem.

Figure 28: Armoured section of Yakamia channel upstream of the Aquatic Centre (2007).

The sediment plumes evident in Figure 28 show that erosion was still active in the upstream catchment at the time the photo was taken. Mobile sediment is naturally deposited in a way that promotes the creation of meanders into a stream channel.

Figure 29: Erosion on the bank of Yakamia Creek caused by stock accessing the water. Photo taken November 2014.

Stock, like you and I, will choose the easiest access point to a stream. Stock pugging destabilises floodway top-soils and create erosion prone pockets that are easily exploited by the next significant flood flow (Figure 29).

Stock defecating directly into Yakamia Creek is an unacceptable source of water contamination, affecting the health of the stream and Oyster Harbour, as well as that of the stock themselves.

Best management practice

Stock should be kept off the banks and out of the stream channel. If they are allowed access for grass control this should only be for a fixed period of time, sufficient to achieve the aim and it should preferably be done when the ground is dry and firm.

Figure 30: Bank collapse under kikuyu grass after the 2008 flood, Photo courtesy of Wilhelm Ficko

Kikuyu provides reasonable armouring of top soils, but is not as effective at stabilizing the toe of high, steep channel banks and preventing bank collapse (Figure 30). Native plants, such as sedges that can grow in this zone and they do a better job.

Figure 31: The water's edge (toe of the bank) of Yakamia Creek where the banks are steep and collapsing (Section D2.4)

The toe of a stream bank is where stream erosive power is strongly expressed. Less consolidated (soil) banks if undermined, collapse under their own weight. This is a common occurrence along the deeper incised sections of Yakamia Creek where bank height may be two or more metres and the soils are weakly consolidated (Figure 31).

Groundwater seepage from upslope of the channel can promote bank slumping in steeply incised gullies.

Ad hoc dumping of rocks in the channel to deal with erosion hotspots can actually aggravate bank erosion in these situations, by increasing local water turbulence.

Better management practice

Soft engineering is using a variety of plants in appropriate zones of the floodway to create a stable channel without compromising drainage efficiency.

In-stream vegetation slows water flow and raises the water level thereby increasing the risk of flows overtopping the bank however fringing vegetation stabilises the banks and broader floodway by reducing the flow velocity.

Well vegetated streams tend to be narrower, deeper and faster flowing than channels lacking stabilizing vegetation (Figure 32). Streams flowing through poorly consolidated soils will tend to widen and become shallow (Figure 33).

Best management practice

The channel cross-sectional area beneath a crossing should match the average cross-sectional area upstream and downstream. Bridges with an adequate span are favored over narrow culvert crossings. For this reason the stable cross-sectional area for a stream channel should not be reduced by more than 10% at a crossing.

Along Yakamia Creek, the larger woody weeds currently act to stabilise the floodway adjacent to the dominant channel, in lieu of the original native vegetation (Figure 32).

Figure 32: A well vegetated section of Yakamia Creek, albeit predominantly with weeds. (Photo courtesy of Sheryn Prior).

Better management practice

Replacement of weed species with native plants and any reconfiguration of the floodway cross-section, will be better supported with block sedges. Although more expensive, these have been shown to be effective. (See the Bannister Creek Case Study in Supplement 1)

Erosion control is synonymous with water velocity control. Therefore the layout and physical structure (density, story composition) of riparian buffering vegetation should be designed to accommodate floodwater that moves out of the dominant channel. Care should be taken to avoid concentrating flood flow paths, thereby increasing flow velocities and creating unwanted erosion hotspots.

Aggressive colonizing weeds that produce long lasting seeds (for example Gorse) must be consistently treated for many years if adequate control and eventual eradication is the goal.

Better management practice

Engage a local 'Friends of' group to assist with weed control.

Figure 33: Yakamia Creek, looking upstream at the crossing and widened channel downstream created by turbulence. (2005 flood photo courtesy of Wilhelm Ficko).

Narrowing the channel at crossings decreases construction costs, but it also increases the local flow velocity, creating a turbulent, highly erosive zone immediately downstream of the crossing outlet. In the situation shown in Figure 33, back eddies acting on unstable banks have widened the channel. In the worst case scenario the crossing itself would eventually collapse.

Better management practice

Channel modifications and maintenance works should be subject to the requirements of a 'whole of stream' development and maintenance plan.

Landholders who provide gates at property boundaries can help facilitate easy access for more efficient maintenance of the floodway. If a holistic management plan is to be implemented along Yakamia Creek easy access for channel maintenance and weed control is important to reduce maintenance costs (Figure 34).

Figure 34: Boundary gate between two properties adjacent to Yakamia Creek. Photo taken November 2014.

The Western tributaries (Tier 2)

The two short western tributaries of Yakamia Creek currently retain significant areas of remnant bushland although this is being degraded through uncontrolled vehicle use and weed invasion. The public currently access the private land downstream of the constructed wetland bounded by Range Road and Callistemon View (tributary F). The most obvious public use of the area is as a dumping ground for rubbish. However, the tracks are also used as an informal walk trail and the recreational use of motorbikes and 4WD's.

Water flow appears to become noticeably channelized approximately 350 meters downstream of Range Road, however the vegetation is very dense and the channel is narrow and shallow as a result. The riparian zone is broad encompassing wetlands with tracks along the interface between the wet areas and the woodland on the fringing slopes.

The upper reach of tributary G is cleared farmland, but further downstream there are areas of fragmented remnant vegetation. The recommended initial action in these areas will be to fence and re-vegetate the streamline to restore continuity of riparian vegetation. Stock watering points are also recommended.

Recommendation

The Oyster Harbour Catchment Group could consider consultation with landholders regarding weed management and the protection of remnant native vegetation as the immediate priority. As mentioned, the implementation of significant on-ground floodway development projects is premature.

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APPENDIX 1: Constraints scoring for each section of Yakamia Creek.

Priority color coding			
	Tier 1	0 - 5	Initial, feasible targets for Living Stream rehabilitation
	Tier 2	6 - 10	Future potential, but with one or two significant issues to take into account.
	Tier 3	11 - 20	Problematic, with multiple development issues to consider
	Tier 4	> 20	Highly constrained (do nothing)

Section	Sum of Constraints	Section length (m)	Section length score	Riparian connectivity up and down stream	Capacity to add channel sinuosity.	Width available for riparian veg.	Capacity to alter cross-section	Conveyance stormwater infrastructure	Land tenure	Land tenure score	Public amenity	Mainten ance
Yak_A01.1	**8**	137.3	0	0	0	0	0	0	Freehold	3	2	3
Yak_A01.2	**7**	44.5	2	3	0	1	0	0	Reserve	0	1	0
Yak_A02	**24**	514.7	0	3	3	3	3	3	Piped	3	3	3
Yak_A03	**15**	31.0	3	3	2	2	0	1	Road reserve	3	1	0
Yak_A04	**23**	70.5	1	3	3	3	3	3	Road reserve	1	3	3
Yak_A05.1	**5**	37.1	2	3	0	0	0	0	Reserve	0	0	0
Yak_A05.2	**2**	111.8	0	1	0	0	0	1	Reserve	0	0	0
Yak_A05.3	**1**	69.7	1	0	0	0	0	0	Reserve	0	0	0
Yak_A05.r	**27**	13.4	3	3	3	3	3	3	Culvert	3	3	3
Yak_A06	**18**	106.6	0	2	3	3	3	2	Easement	1	2	2
Yak_A06.r	**27**	24.1	3	3	3	3	3	3	Culvert	3	3	3

Section	Sum of Constraints	Section length (m)	Section length score	Riparian connectivity up and down stream	Capacity to add channel sinuosity.	Width available for riparian veg.	Capacity to alter cross-section	Conveyance stormwater infrastructure	Land tenure	Land tenure score	Public amenity	Mainten ance
Yak_A07	**9**	41.4	2	3	2	0	0	0	Road reserve	1	1	0
Yak_A08	**12**	91.9	1	3	0	0	0	3	Reserve & Freehold	3	2	0
Yak_A09	**9**	27.6	3	3	0	0	0	2	Reserve	0	1	0
Yak_A10	**24**	203.0	0	3	3	3	3	3	Easement	3	3	3
Yak_A11	**4**	66.2	1	3	0	0	0	0	Reserve	0	0	0
Yak_B1	**12**	72.4	1	1	1	1	0	1	Freehold	3	1	3
Yak_B2	**7**	163.6	0	0	0	0	0	0	Freehold	3	1	3
Yak_B3	**10**	47.1	1	0	0	0	0	0	Freehold	3	3	3
Yak_B4	**8**	66.6	1	1	3	2	0	1	Road reserve	0	0	0
Yak_B4.r	**27**	15.4	3	3	3	3	3	3	Culvert	3	3	3
Yak_B5	**10**	64.2	1	1	2	0	0	0	Freehold	3	0	3
Yak_B6.1	**1**	127.9	0	0	0	0	0	1	Reserve	0	0	0
Yak_B6.2	**2**	73.1	1	0	0	0	0	1	Reserve	0	0	0
Yak_B7	**1**	194.4	0	0	0	0	0	1	Reserve	0	0	0

Section	Sum of Constraints	Section length (m)	Section length score	Riparian connectivity up and down stream	Capacity to add channel sinuosity.	Width available for riparian veg.	Capacity to alter cross-section	Conveyance stormwater infrastructure	Land tenure	Land tenure score	Public amenity	Mainten ance
Yak_B8	**5**	138.7	0	3	1	0	0	1	Reserve	0	0	0
Yak_B9	**24**	129.3	0	3	3	3	3	3	Piped	3	3	3
Yak_C1	**5**	170.6	0	3	1	0	0	1	Reserve	0	0	0
Yak_C2	**2**	86.2	1	1	0	0	0	0	Reserve	0	0	0
Yak_C3	**0**	124.1	0	0	0	0	0	0	Reserve	0	0	0
Yak_C4	**5**	134.0	0	0	2	1	0	2	Reserve	0	0	0
Yak_C5	**10**	83.0	1	0	3	2	2	2	Reserve	0	0	0
Yak_C6	**9**	90.7	1	1	3	2	0	2	Reserve	0	0	0
Yak_C6.r	**27**	18.4	3	3	3	3	3	3	Culvert	3	3	3
Yak_C7	**15**	99.8	0	2	3	3	3	2	Reserve	2	0	0
Yak_C8	**6**	127.5	0	2	1	1	0	2	Reserve	0	0	0
Yak_C8.r	**27**	16.5	3	3	3	3	3	3	Culvert	3	3	3
Yak_C9.1	**4**	149.8	0	1	0	1	0	2	Reserve	0	0	0
Yak_C9.2	**3**	122.8	0	3	0	0	0	0	Reserve	0	0	0
Yak_C10	**27**	75.6	3	3	3	3	3	3	Piped	3	3	3

Section	Sum of Constraints	Section length (m)	Section length score	Riparian connectivity up and down stream	Capacity to add channel sinuosity.	Width available for riparian veg.	Capacity to alter cross-section	Conveyance stormwater infrastructure	Land tenure	Land tenure score	Public amenity	Mainten ance
Yak_Ct1	**4**	254.6	0	3	0	0	0	1	Reserve	0	0	0
Yak_Ct2	**24**	359.3	0	3	3	3	3	3	Piped	3	3	3
Yak_Ct3	**4**	249.9	0	3	0	0	0	1	Reserve	0	0	0
Yak_Ct4	**1**	81.7	1	0	0	0	0	0	Reserve	0	0	0
Yak_Ct5	**7**	206.2	0	1	3	2	1	0	Reserve	0	0	0
Yak_Ct6	**3**	181.6	0	0	0	0	3	0	Reserve	0	0	0
Yak_Ct7	**1**	100.8	0	0	1	0	0	0	Reserve	0	0	0
Yak_Ct8	**16**	23.6	3	3	3	2	3	2	Reserve	0	0	0
Yak_Ct8.r	**27**	13.3	3	3	3	3	3	3	Culvert	3	3	3
Yak_D1.1	**6**	138.1	0	1	2	0	1	0	Reserve	0	2	0
Yak_D1.2	**4**	265.7	0	0	1	0	0	1	Reserve	0	2	0
Yak_D2.1	**10**	217.2	0	0	0	0	0	1	Freehold	3	3	3
Yak_D2.2	**6**	118.3	0	0	0	0	0	0	Easement	1	3	2
Yak_D2.3	**7**	83.4	1	0	0	0	0	0	Easement	1	3	2
Yak_D2.4	**6**	86.4	1	0	0	0	0	0	Reserve	0	3	2

Section	Sum of Constraints	Section length (m)	Section length score	Riparian connectivity up and down stream	Capacity to add channel sinuosity.	Width available for riparian veg.	Capacity to alter cross-section	Conveyance stormwater infrastructure	Land tenure	Land tenure score	Public amenity	Mainten ance
Yak_D2.5	**7**	91.1	1	0	0	0	0	0	Easement	1	3	2
Yak_D2.6	**8**	65.5	1	0	0	0	0	1	Easement	1	3	2
Yak_D2.7	**6**	99.3	1	0	0	0	0	0	Reserve	0	3	2
Yak_D3.1	**9**	104.9	0	0	0	0	0	0	Freehold	3	3	3
Yak_D3.2	**9**	100.8	0	0	0	0	0	0	Freehold	3	3	3
Yak_D3.3	**10**	110.2	0	0	0	0	0	1	Freehold	3	3	3
Yak_D4.1	**9**	113.5	0	0	0	0	0	0	Freehold	3	3	3
Yak_D4.2	**9**	204.2	0	0	0	0	0	0	Freehold	3	3	3
Yak_D4.3	**9**	104.9	0	0	0	0	0	0	Freehold	3	3	3
Yak_D4.4	**6**	178.7	0	0	0	0	0	1	Reserve	0	3	2
Yak_D4.5	**9**	102.4	0	0	0	0	0	0	Freehold	3	3	3
Yak_D4.6	**10**	71.2	1	0	0	0	0	0	Freehold	3	3	3
Yak_D4.7	**10**	72.7	1	0	0	0	0	0	Freehold	3	3	3
Yak_D4.8	**9**	196.7	0	0	0	0	0	0	Freehold	3	3	3
Yak_D5.1	**9**	122.7	0	0	0	0	0	0	Freehold	3	3	3

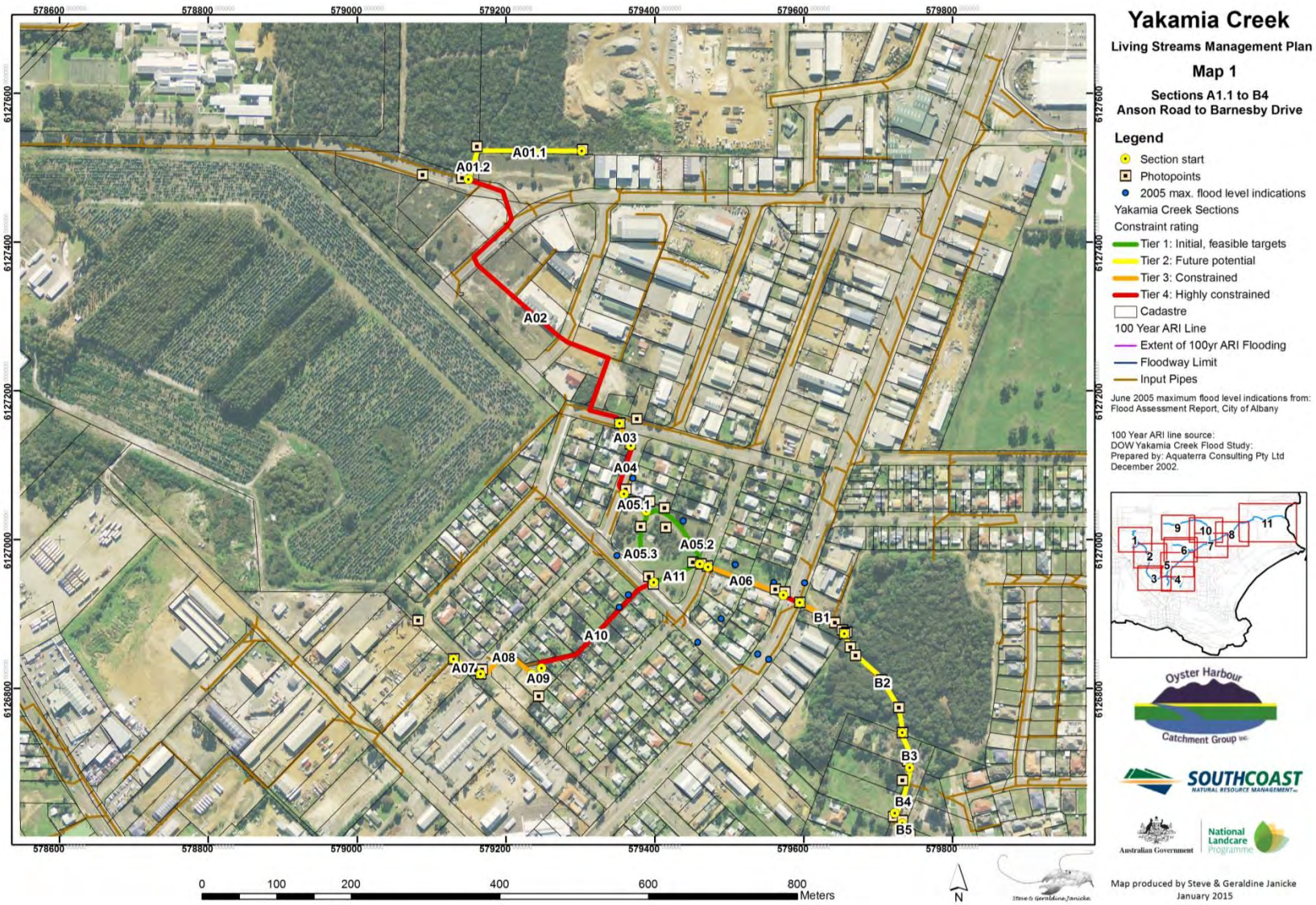
Section	Sum of Constraints	Section length (m)	Section length score	Riparian connectivity up and down stream	Capacity to add channel sinuosity.	Width available for riparian veg.	Capacity to alter cross-section	Conveyance stormwater infrastructure	Land tenure	Land tenure score	Public amenity	Mainten ance
Yak_D5.2	**9**	160.8	0	0	0	0	0	0	Freehold	3	3	3
Yak_D5.3	**9**	205.9	0	0	0	0	0	0	Freehold	3	3	3
Yak_D5.4	**9**	238.3	0	0	0	0	0	0	Freehold	3	3	3
Yak_D5.5	**9**	210.0	0	0	0	0	0	0	Freehold	3	3	3
Yak_D5.6	**10**	64.2	1	0	0	0	0	0	Freehold	3	3	3
Yak_D5.7	**9**	307.9	0	0	0	0	0	0	Freehold	3	3	3
Yak_D5.8	**9**	358.6	0	0	0	0	0	0	Freehold	3	3	3
Yak_D5.9	**6**	72.1	1	1	0	0	0	1	Road reserve	1	2	0
Yak_D5.r	**24**	14.1	3	3	3	3	3	0	Culvert	3	3	3
Yak_E1	**10**	198.3	0	1	0	0	0	0	Freehold	3	3	3
Yak_E1.r	**18**	26.1	3	3	3	3	3	0	Road reserve	1	2	0
Yak_E2	**9**	666.0	0	0	0	0	0	0	Freehold	3	3	3
Yak_E3.1	**9**	431.7	0	0	0	0	0	0	Freehold	3	3	3
Yak_E3.2	**9**	377.2	0	0	0	0	0	0	Freehold	3	3	3
Yak_E4	**4**	210.3	0	0	0	0	0	0	Reserve	0	2	2

Section	Sum of Constraints	Section length (m)	Section length score	Riparian connectivity up and down stream	Capacity to add channel sinuosity.	Width available for riparian veg.	Capacity to alter cross-section	Conveyance stormwater infrastructure	Land tenure	Land tenure score	Public amenity	Mainten ance
Yak_E5	**4**	157.6	0	0	0	0	0	0	Reserve	0	2	2
Yak_F1.1	**10**	206.8	0	1	0	0	0	0	Freehold	3	3	3
Yak_F1.2	**9**	209.9	0	0	0	0	0	0	Freehold	3	3	3
Yak_F1.3	**9**	225.0	0	0	0	0	0	0	Freehold	3	3	3
Yak_F1.4	**11**	49.9	2	0	0	0	0	0	Freehold	3	3	3
Yak_F1.5	**9**	161.1	0	0	0	0	0	0	Freehold	3	3	3
Yak_G1.1	**9**	231.7	0	0	0	0	0	0	Freehold	3	3	3
Yak_G1.2	**9**	254.2	0	0	0	0	0	0	Freehold	3	3	3
Yak_G1.3	**9**	242.4	0	0	0	0	0	0	Freehold	3	3	3
Yak_G2	**9**	366.5	0	0	0	0	0	0	Freehold	3	3	3
Yak_G2.r	**10**	21.2	3	0	3	0	0	0	Road reserve	1	2	1
Yak_G3.1	**9**	120.7	0	0	0	0	0	0	Freehold	3	3	3
Yak_G3.2	**9**	121.0	0	0	0	0	0	0	Freehold	3	3	3
Yak_G3.3	**9**	143.9	0	0	0	0	0	0	Freehold	3	3	3
Yak_G3.4	**9**	131.5	0	0	0	0	0	0	Freehold	3	3	3

Section	Sum of Constraints	Section length (m)	Section length score	Riparian connectivity up and down stream	Capacity to add channel sinuosity.	Width available for riparian veg.	Capacity to alter cross-section	Conveyance stormwater infrastructure	Land tenure	Land tenure score	Public amenity	Mainten ance
Yak_G3.5	**9**	214.1	0	0	0	0	0	0	Freehold	3	3	3
Yak_G3.6	**11**	43.7	2	0	0	0	0	0	Freehold	3	3	3
Yak_G3.r	**10**	24.4	3	0	3	0	0	0	Road reserve	1	2	1
Yak_G4.1	**9**	278.8	0	0	0	0	0	0	Freehold	3	3	3
Yak_G4.2	**9**	111.4	0	0	0	0	0	0	Freehold	3	3	3
Yak_G5.1	**8**	218.3	0	0	2	1	0	0	Road reserve	1	2	2
Yak_G5.2	**8**	199.5	0	0	2	1	0	0	Road reserve	1	2	2
Yak_G5.3	**9**	105.2	0	0	0	0	0	0	Freehold	3	3	3

APPENDIX 2: Section Maps

The Section Maps are on the following pages.



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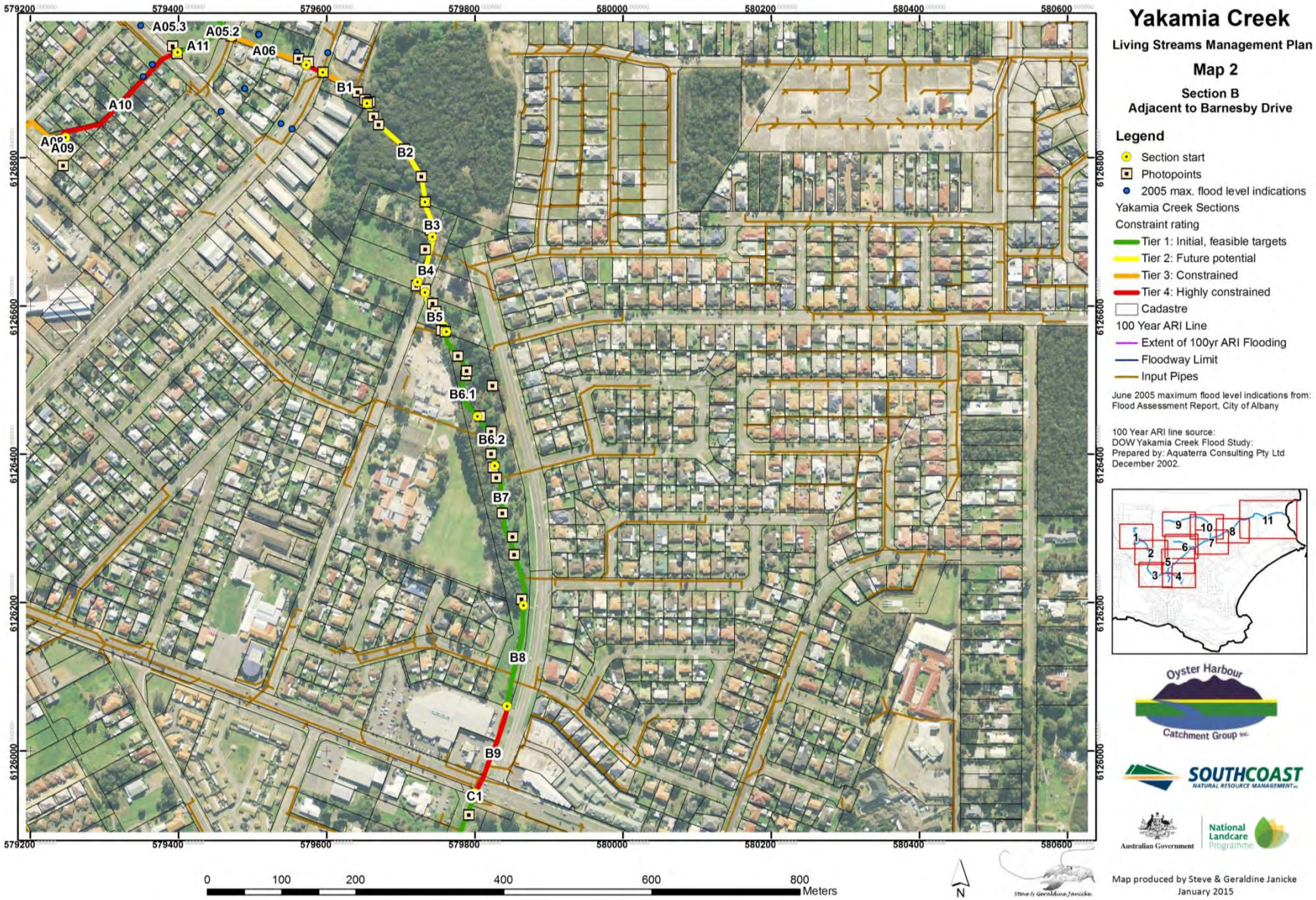
Yakamia Creek
Living Streams Management Plan
Map 2
Section B
Adjacent to Barnesby Drive
Legend
Section start
Photopoints
2005 max. flood level indications
Yakamia Creek Sections
Constraint rating
Tier 1: Initial, feasible targets
Tier 2: Future potential
Tier 3: Constrained
Tier 4: Highly constrained
Cadastre
100 Year ARI Line
Extent of 100yr ARI Flooding
Floodway Limit
Input Pipes
June 2005 maximum flood level indications from: Flood Assessment Report, City of Albany
100 Year ARI line source: DOW Yakamia Creek Flood Study: Prepared by: Aquaterra Consulting Pty Ltd December 2002.
A05.3
A05.2
A11
A06
A10
A09
B1
B2
B3
B4
B5
B6.1
B6.2
B7
B8
B9
C1
0 100 200 400 600 800 Meters
N
Map produced by Steve & Geraldine Janicke January 2015
Oyster Harbour Catchment Group
SOUTHCOAST
Australian Government
National Landcare Programme
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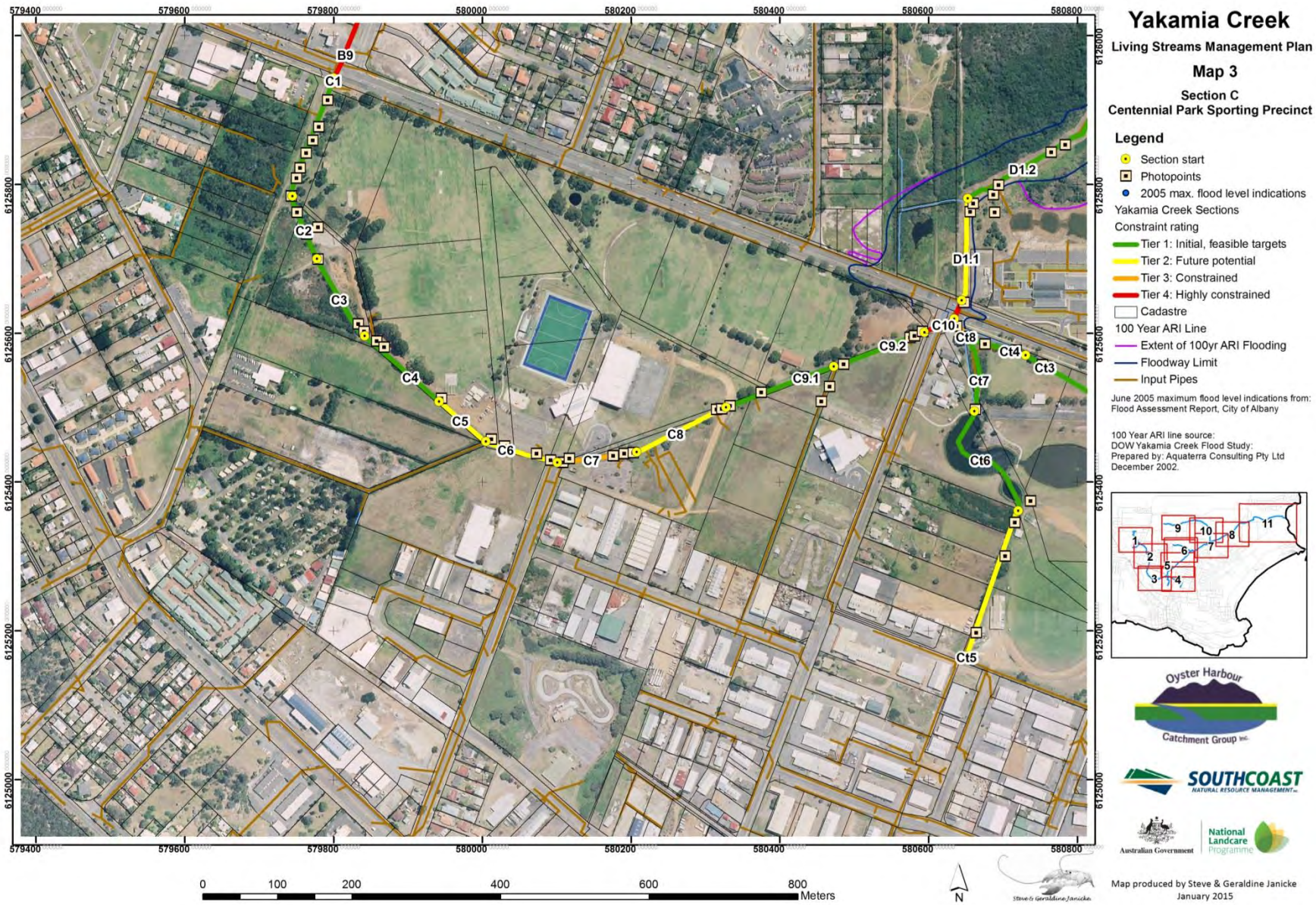
Yakamia Creek
Living Streams Management Plan
Map 3
Section C
Centennial Park Sporting Precinct
Legend
Section start
Photopoints
2005 max. flood level indications
Yakamia Creek Sections
Constraint rating
Tier 1: Initial, feasible targets
Tier 2: Future potential
Tier 3: Constrained
Tier 4: Highly constrained
Cadastre
100 Year ARI Line
Extent of 100yr ARI Flooding
Floodway Limit
Input Pipes
June 2005 maximum flood level indications from: Flood Assessment Report, City of Albany
100 Year ARI line source: DOW Yakamia Creek Flood Study: Prepared by: Aquaterra Consulting Pty Ltd December 2002.
B9
C1
C2
C3
C4
C5
C6
C7
C8
C9.1
C9.2
C10.1
D1.1
D1.2
Ct3
Ct4
Ct5
Ct6
Ct7
Ct8
579400
579600
579800
580000
580200
580400
580600
580800
6125800
6125600
6125400
6125200
6125000
6126000
0
100
200
400
600
800
Meters
N
Oyster Harbour Catchment Group Inc.
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National Landcare Programme
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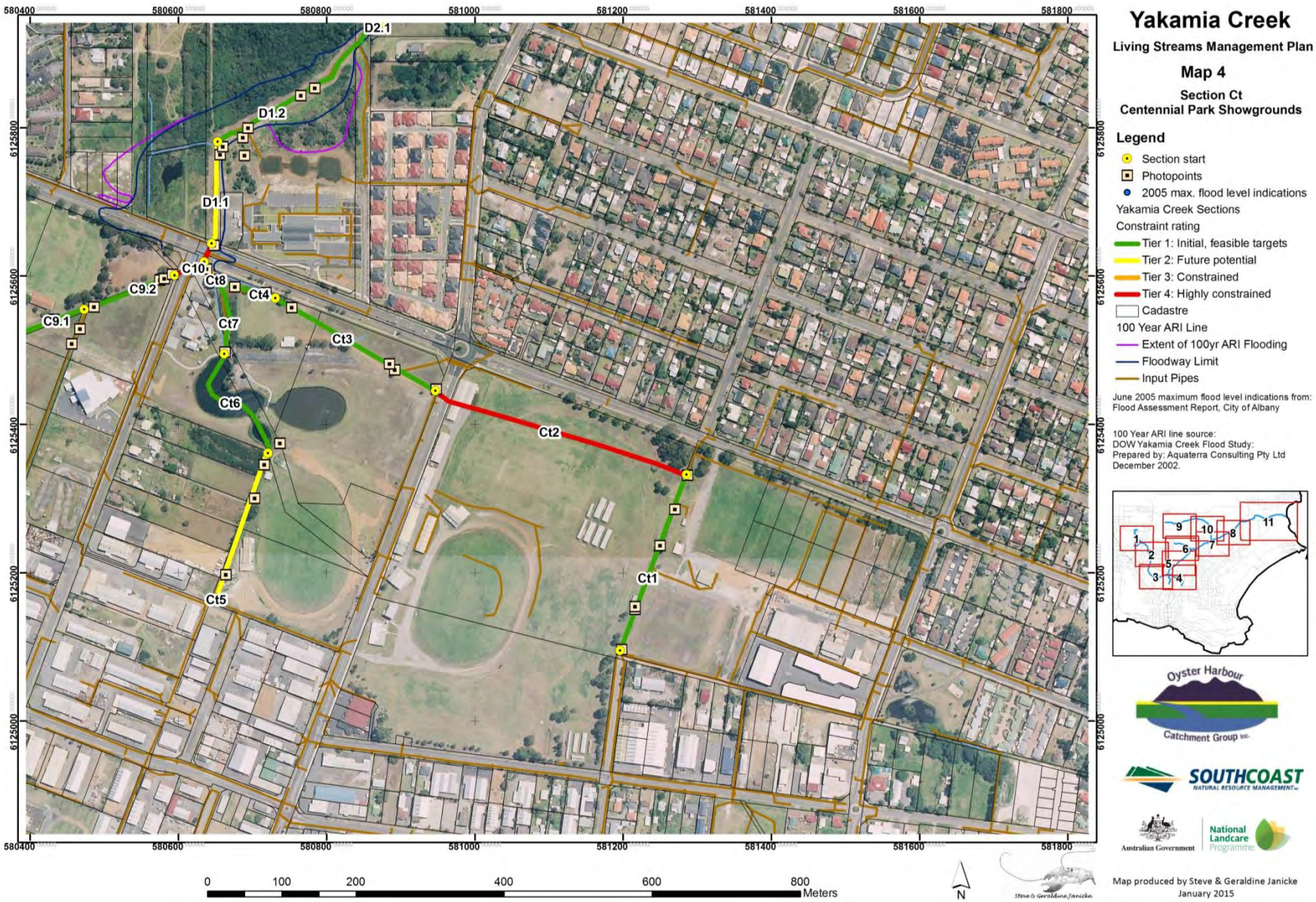
Yakamia Creek
Living Streams Management Plan
Map 4
Section Ct
Centennial Park Showgrounds
Legend
Section start
Photopoints
2005 max. flood level indications
Yakamia Creek Sections
Constraint rating
Tier 1: Initial, feasible targets
Tier 2: Future potential
Tier 3: Constrained
Tier 4: Highly constrained
Cadastre
100 Year ARI Line
Extent of 100yr ARI Flooding
Floodway Limit
Input Pipes
June 2005 maximum flood level indications from: Flood Assessment Report, City of Albany
100 Year ARI line source: DOW Yakamia Creek Flood Study; Prepared by: Aquaterra Consulting Pty Ltd December 2002.
D2.1
D1.2
D1.1
C10.1
C9.2
C9.1
Ct8
Ct4
Ct7
Ct3
Ct6
Ct2
Ct1
Ct5
580400
580600
580800
581000
581200
581400
581600
581800
6125800
6125600
6125400
6125200
6125000
0
100
200
400
600
800
Meters
N
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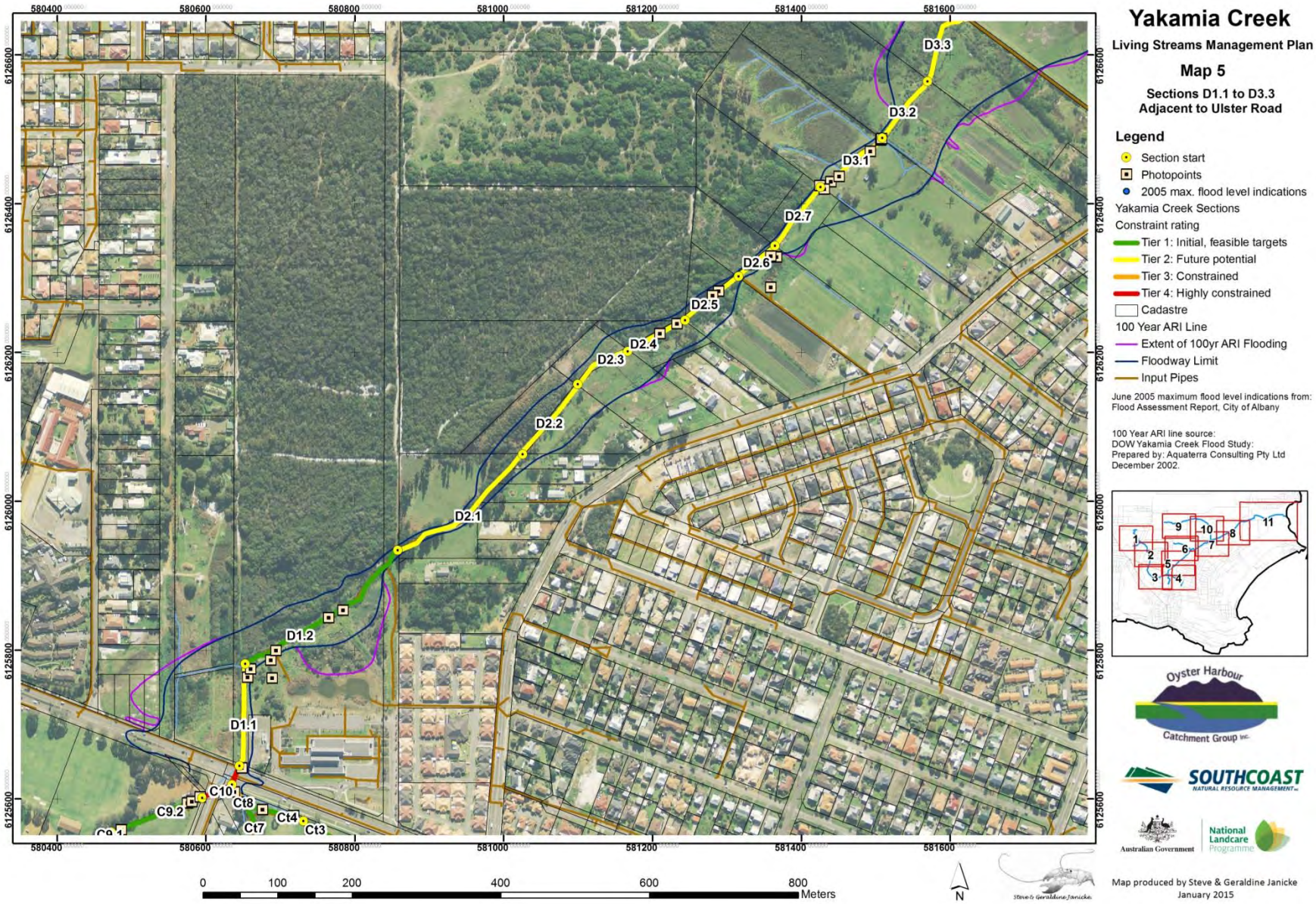
Yakamia Creek
Living Streams Management Plan
Map 5
Sections D1.1 to D3.3
Adjacent to Ulster Road
Legend
Section start
Photopoints
2005 max. flood level indications
Yakamia Creek Sections
Constraint rating
Tier 1: Initial, feasible targets
Tier 2: Future potential
Tier 3: Constrained
Tier 4: Highly constrained
Cadastre
100 Year ARI Line
Extent of 100yr ARI Flooding
Floodway Limit
Input Pipes
June 2005 maximum flood level indications from:
Flood Assessment Report, City of Albany
100 Year ARI line source:
DOW Yakamia Creek Flood Study:
Prepared by: Aquaterra Consulting Pty Ltd
December 2002.
D3.3
D3.2
D3.1
D2.7
D2.6
D2.5
D2.4
D2.3
D2.2
D2.1
D1.2
D1.1
C10.1
C9.2
Ct8
Ct7
Ct4
Ct3
580400
580600
580800
581000
581200
581400
581600
6126600
6126400
6126200
6126000
6125800
6125600
0
100
200
400
600
800
Meters
N
Oyster Harbour
Catchment Group Inc.
SOUTHCOAST
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Australian Government
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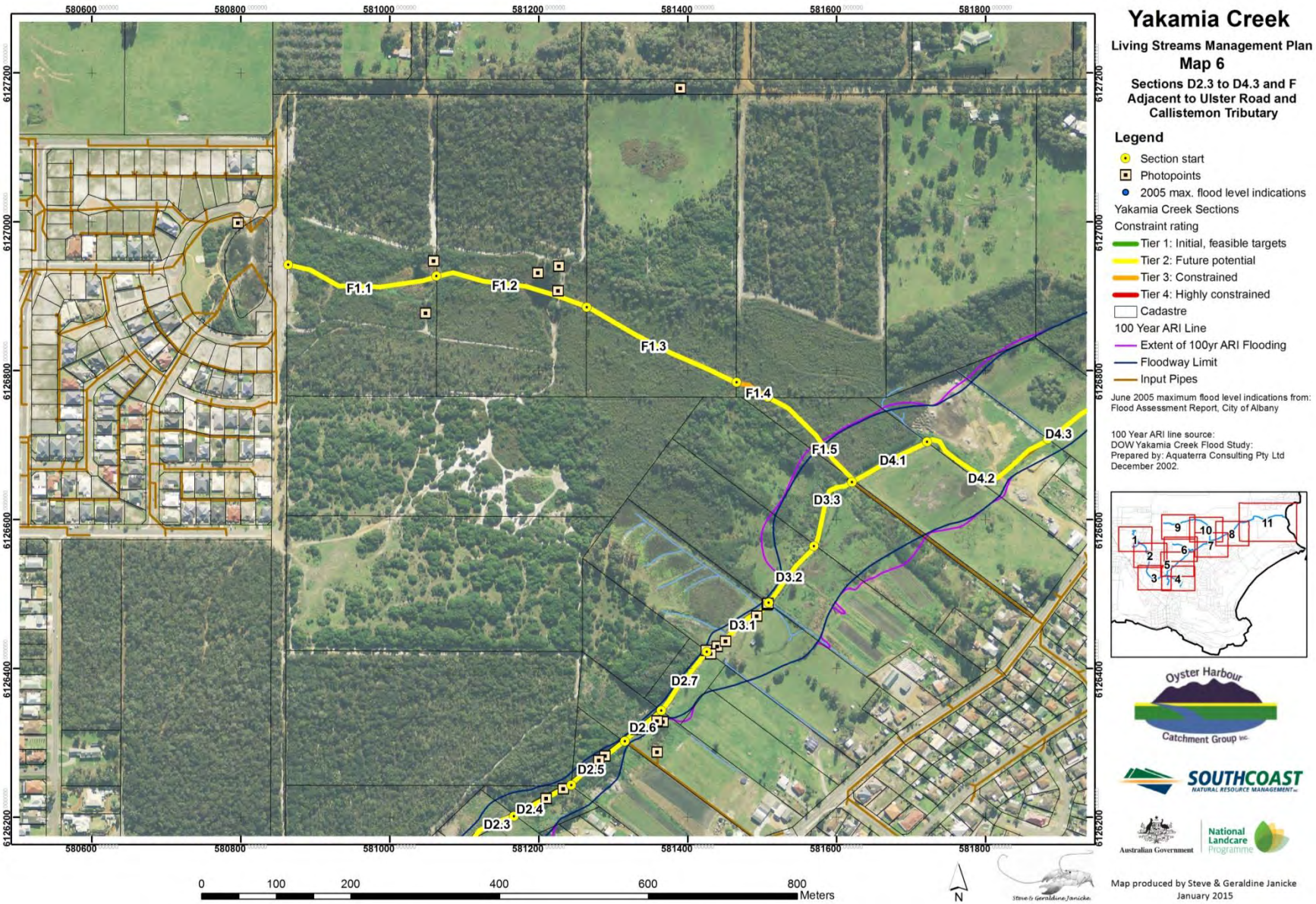
Yakamia Creek
Living Streams Management Plan
Map 6
Sections D2.3 to D4.3 and F Adjacent to Ulster Road and Callistemon Tributary
Legend
Section start
Photopoints
2005 max. flood level indications
Yakamia Creek Sections
Constraint rating
Tier 1: Initial, feasible targets
Tier 2: Future potential
Tier 3: Constrained
Tier 4: Highly constrained
Cadastre
100 Year ARI Line
Extent of 100yr ARI Flooding
Floodway Limit
Input Pipes
June 2005 maximum flood level indications from: Flood Assessment Report, City of Albany
100 Year ARI line source: DOW Yakamia Creek Flood Study: Prepared by: Aquaterra Consulting Pty Ltd December 2002.
F1.1
F1.2
F1.3
F1.4
F1.5
D4.1
D4.2
D4.3
D3.3
D3.2
D3.1
D2.7
D2.6
D2.5
D2.4
D2.3
580600
580800
581000
581200
581400
581600
581800
6127200
6127000
6126800
6126600
6126400
6126200
0
100
200
400
600
800
Meters
N
Oyster Harbour Catchment Group Inc.
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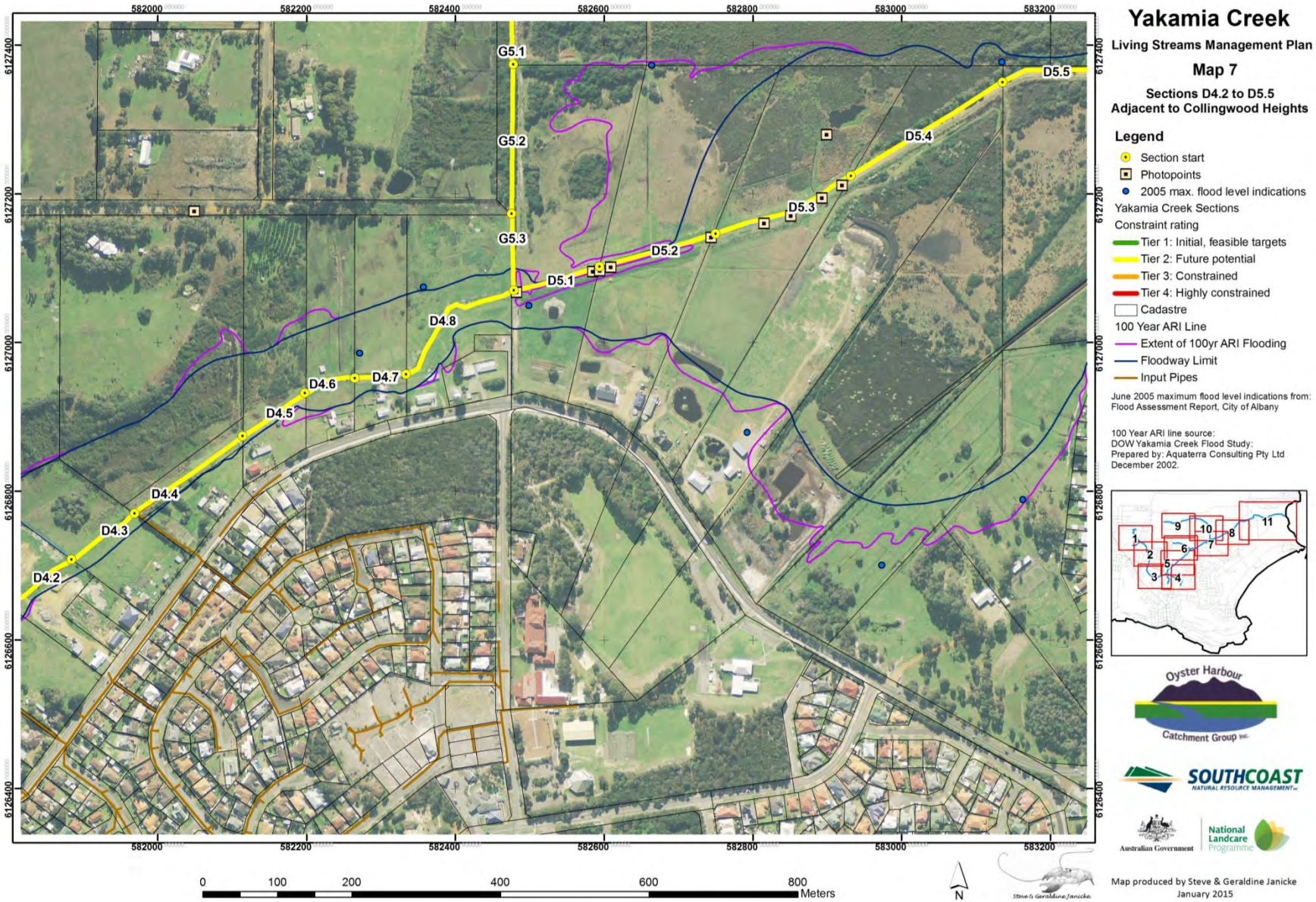
Yakamia Creek
Living Streams Management Plan
Map 7
Sections D4.2 to D5.5
Adjacent to Collingwood Heights
Legend
Section start
Photopoints
2005 max. flood level indications
Yakamia Creek Sections
Constraint rating
Tier 1: Initial, feasible targets
Tier 2: Future potential
Tier 3: Constrained
Tier 4: Highly constrained
Cadastre
100 Year ARI Line
Extent of 100yr ARI Flooding
Floodway Limit
Input Pipes
June 2005 maximum flood level indications from:
Flood Assessment Report, City of Albany
100 Year ARI line source:
DOW Yakamia Creek Flood Study:
Prepared by: Aquaterra Consulting Pty Ltd
December 2002.
G5.1
G5.2
G5.3
D5.1
D5.2
D5.3
D5.4
D5.5
D4.2
D4.3
D4.4
D4.5
D4.6
D4.7
D4.8
582000
582200
582400
582600
582800
583000
583200
6127400
6127200
6127000
6126800
6126600
6126400
0
100
200
400
600
800
Meters
N
Oyster Harbour
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National Landcare Programme
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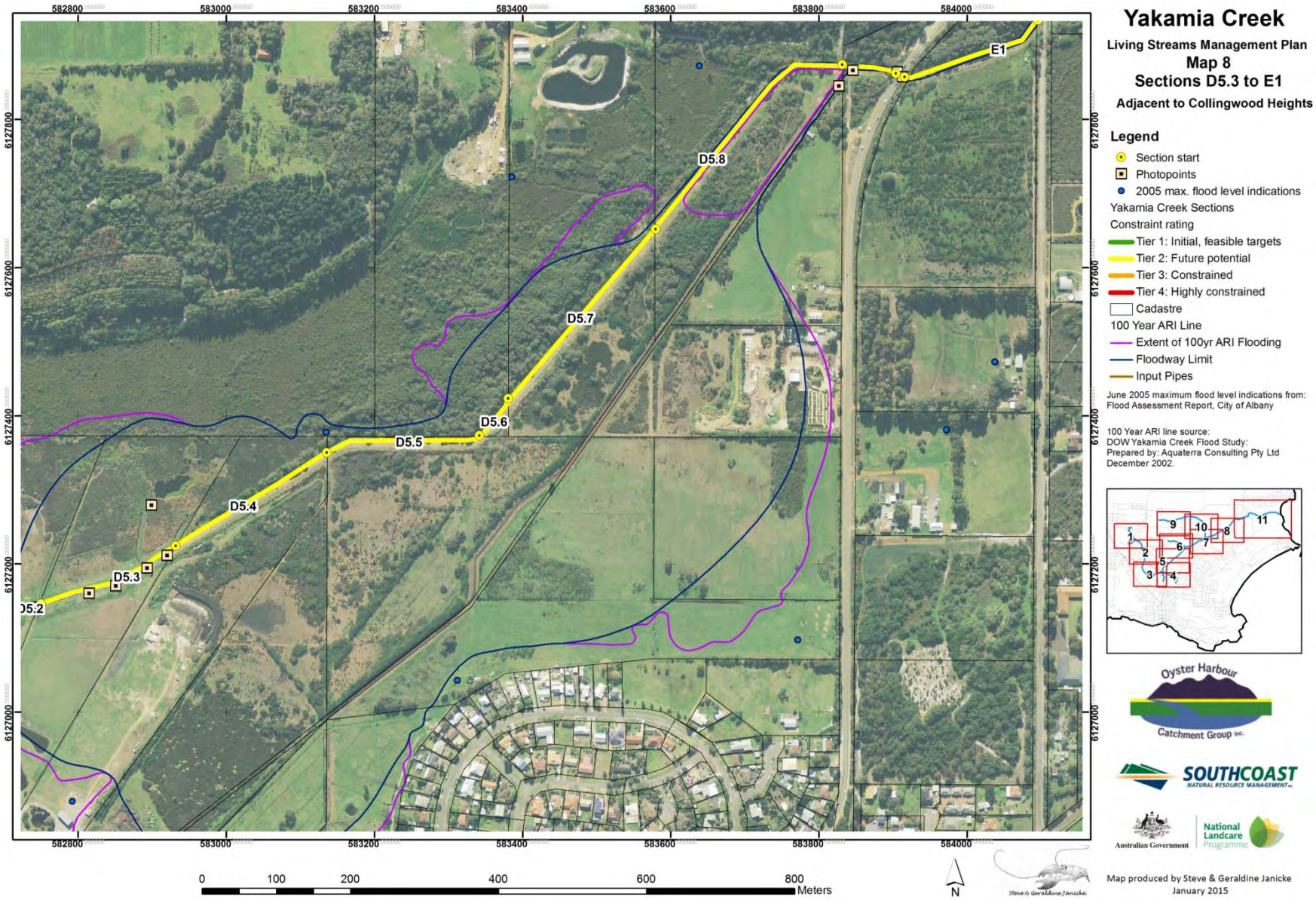
Yakamia Creek
Living Streams Management Plan
Map 8
Sections D5.3 to E1
Adjacent to Collingwood Heights
Legend
Section start
Photopoints
2005 max. flood level indications
Yakamia Creek Sections
Constraint rating
Tier 1: Initial, feasible targets
Tier 2: Future potential
Tier 3: Constrained
Tier 4: Highly constrained
Cadastre
100 Year ARI Line
Extent of 100yr ARI Flooding
Floodway Limit
Input Pipes
June 2005 maximum flood level indications from: Flood Assessment Report, City of Albany
100 Year ARI line source: DOW Yakamia Creek Flood Study: Prepared by: Aquaterra Consulting Pty Ltd December 2002.
D5.2
D5.3
D5.4
D5.5
D5.6
D5.7
D5.8
E1
582800
583000
583200
583400
583600
583800
584000
6127800
6127600
6127400
6127200
6127000
0
100
200
400
600
800
Meters
N
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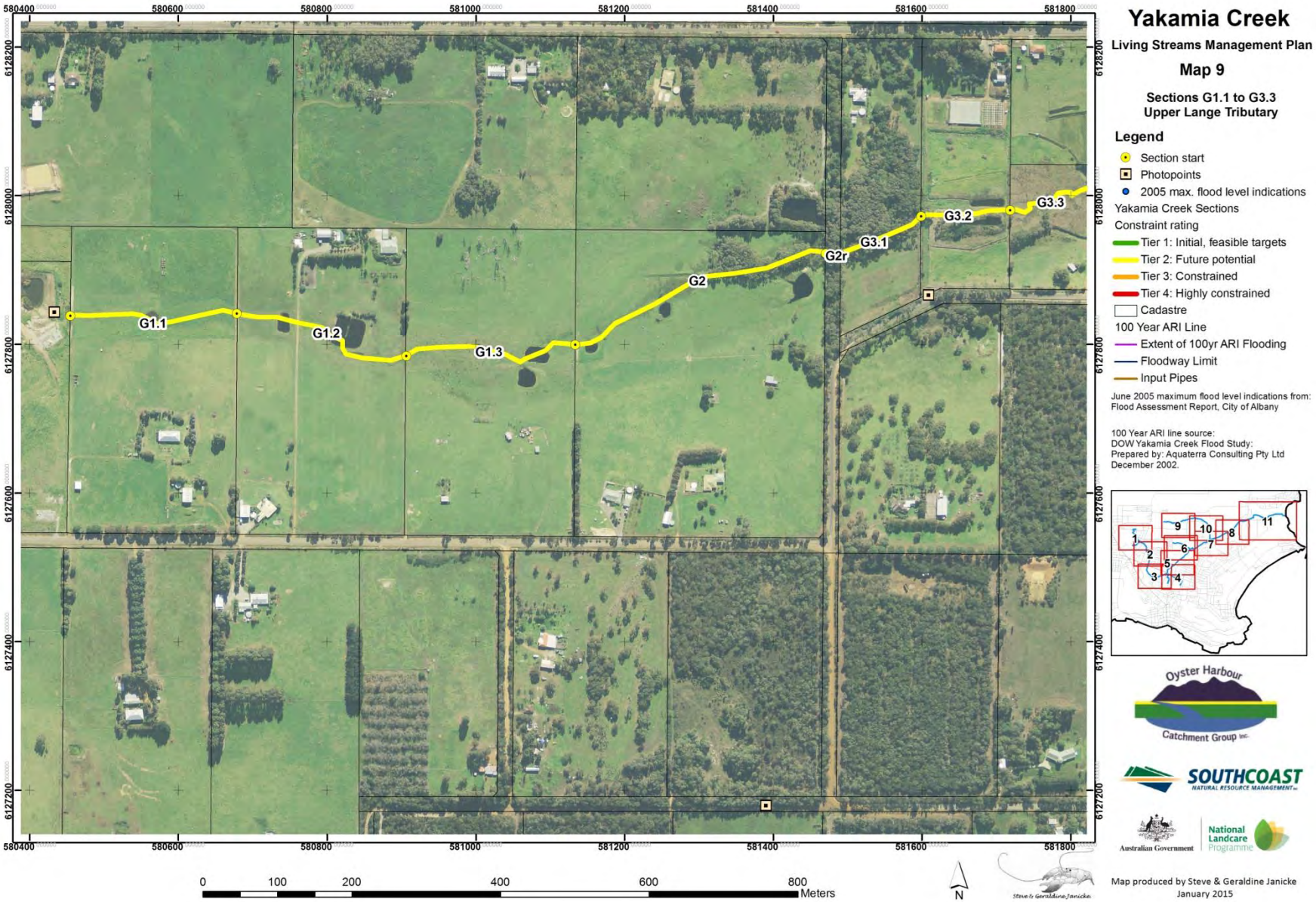
Yakamia Creek
Living Streams Management Plan
Map 9
Sections G1.1 to G3.3
Upper Lange Tributary
Legend
Section start
Photopoints
2005 max. flood level indications
Yakamia Creek Sections
Constraint rating
Tier 1: Initial, feasible targets
Tier 2: Future potential
Tier 3: Constrained
Tier 4: Highly constrained
Cadastre
100 Year ARI Line
Extent of 100yr ARI Flooding
Floodway Limit
Input Pipes
June 2005 maximum flood level indications from: Flood Assessment Report, City of Albany
100 Year ARI line source: DOW Yakamia Creek Flood Study: Prepared by: Aquaterra Consulting Pty Ltd December 2002.
G1.1
G1.2
G1.3
G2
G2r
G3.1
G3.2
G3.3
580400
580600
580800
581000
581200
581400
581600
581800
6128200
6128000
6127800
6127600
6127400
6127200
0
100
200
400
600
800
Meters
N
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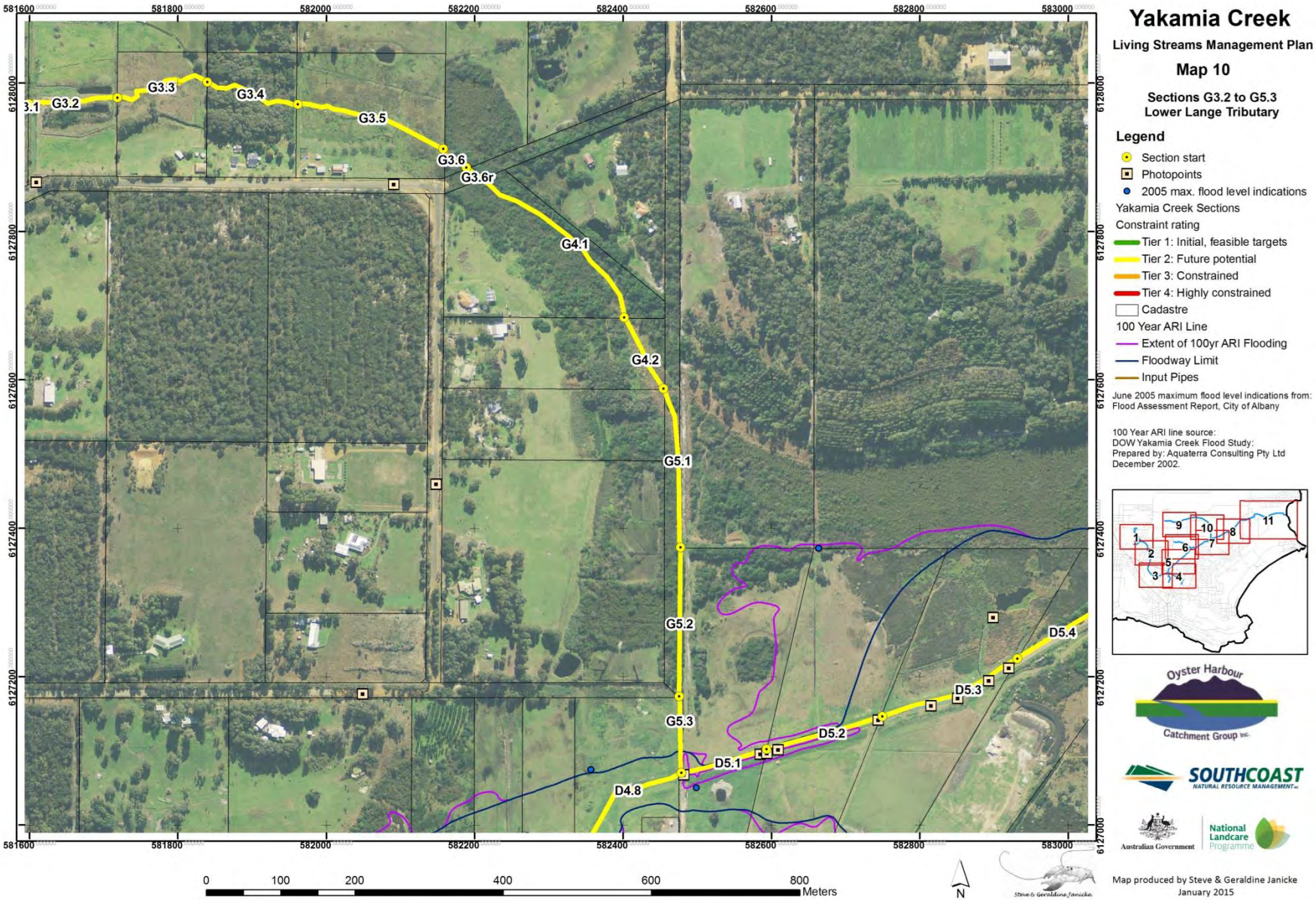
Yakamia Creek
Living Streams Management Plan
Map 10
Sections G3.2 to G5.3
Lower Lange Tributary
Legend
Section start
Photopoints
2005 max. flood level indications
Yakamia Creek Sections
Constraint rating
Tier 1: Initial, feasible targets
Tier 2: Future potential
Tier 3: Constrained
Tier 4: Highly constrained
Cadastre
100 Year ARI Line
Extent of 100yr ARI Flooding
Floodway Limit
Input Pipes
June 2005 maximum flood level indications from: Flood Assessment Report, City of Albany
100 Year ARI line source: DOW Yakamia Creek Flood Study: Prepared by: Aquaterra Consulting Pty Ltd December 2002.
G3.2
G3.3
G3.4
G3.5
G3.6
G3.6r
G4.1
G4.2
G5.1
G5.2
G5.3
D4.8
D5.1
D5.2
D5.3
D5.4
0 100 200 400 600 800 Meters
N
Oyster Harbour Catchment Group Inc.
SOUTHCOAST NATURAL RESOURCE MANAGEMENT Inc.
Australian Government
National Landcare Programme
Map produced by Steve & Geraldine Janicke January 2015
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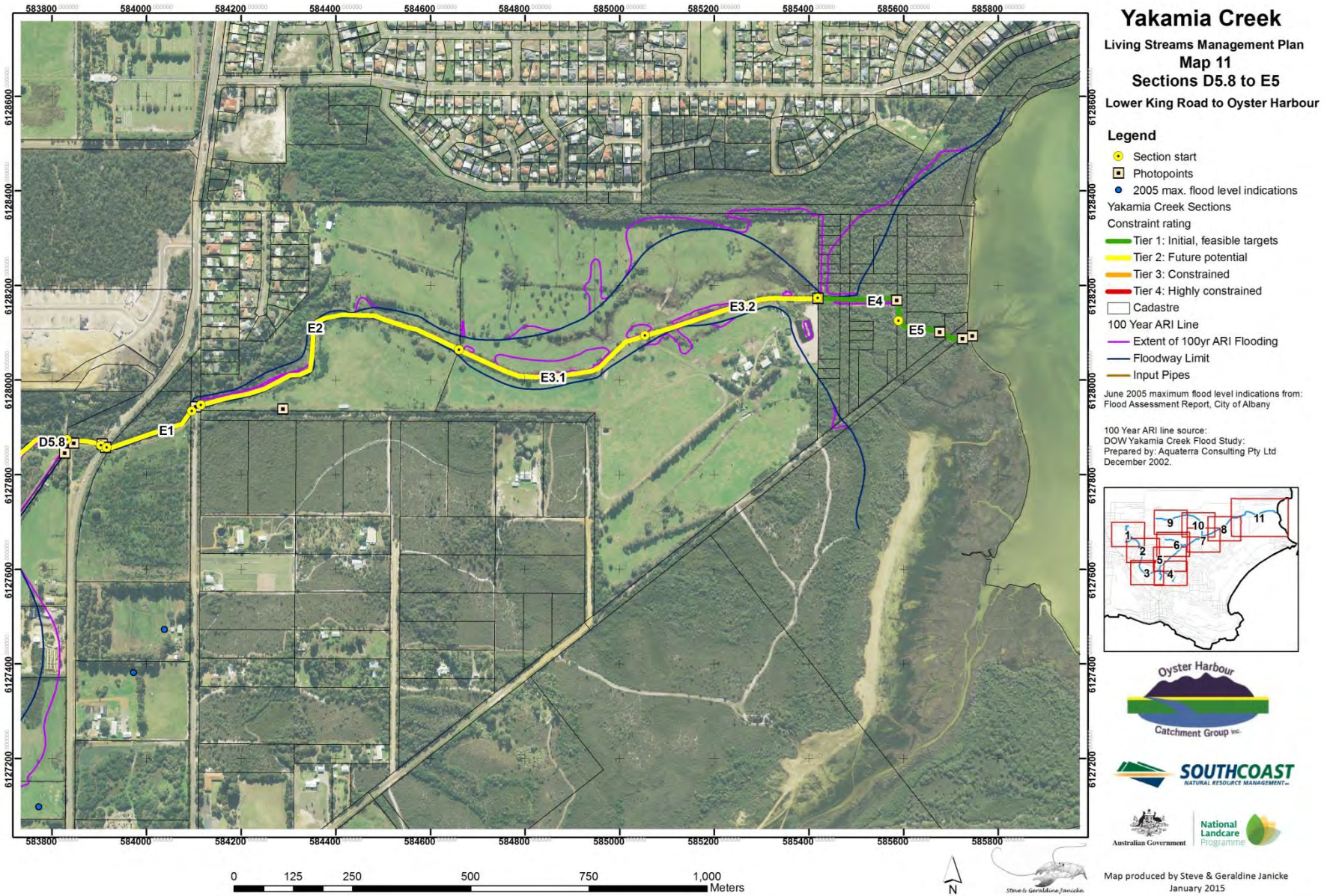
Yakamia Creek
Living Streams Management Plan
Map 11
Sections D5.8 to E5
Lower King Road to Oyster Harbour
Legend
Section start
Photopoints
2005 max. flood level indications
Yakamia Creek Sections
Constraint rating
Tier 1: Initial, feasible targets
Tier 2: Future potential
Tier 3: Constrained
Tier 4: Highly constrained
Cadastre
100 Year ARI Line
Extent of 100yr ARI Flooding
Floodway Limit
Input Pipes
June 2005 maximum flood level indications from: Flood Assessment Report, City of Albany
100 Year ARI line source: DOW Yakamia Creek Flood Study: Prepared by: Aquaterra Consulting Pty Ltd December 2002.
D5.8
E1
E2
E3.1
E3.2
E4
E5
583800
584000
584200
584400
584600
584800
585000
585200
585400
585600
585800
6128600
6128400
6128200
6128000
6127800
6127600
6127400
6127200
0
125
250
500
750
1,000
Meters
N
Oyster Harbour Catchment Group Inc.
SOUTHCOAST NATURAL RESOURCE MANAGEMENT Inc.
Australian Government
National Landcare Programme
Map produced by Steve & Geraldine Janicke
January 2015
Steve & Geraldine Janicke

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APPENDIX 3: Use of Unmanned Aerial vehicles

Ecosystem management and change monitoring – a trial study at the Western End of Centennial Park Sporting Precinct.

In 2014, a trial use of an Unmanned Aerial Vehicle (UAV) was undertaken to look at its capacity to provide detailed ecosystem mapping. The UAV incorporated 'Point Cloud' photographic technology.

The process of taking a broad concept plan and creating an accurate working plan of an area requires greater detail of ecosystem features in the target area. In the case of stream rehabilitation or restoration, accurate cross-sections and bed slopes provide the essential data for determining the primary hydraulic characteristics of the floodway. These are usually obtained by on-ground surveying methods. The data also enables an analysis of the likely hydraulic impacts of any proposed modifications.

However, the other components of the ecosystem, chiefly vegetation, habitat structure, micro-topography and so on, are more difficult and costly to survey in detail. As a result soft engineering has had to rely on less rigorous mapping techniques, essentially adding further site observations to a base concept plan. Rehabilitation sites are often too small for standard aerial images to be of more than general usefulness in this respect, although technical improvements are raising the standard of image resolution.

The recent and rapid development of remote sensing equipment with high-resolution imagery offers a tool for the urban ecologist to create working plans at a level comparable with traditional surveying methods, but with greater detail. This can be used to model various project scenarios.

Airborne laser scanning offers foundation mapping of the 'bare-earth' micro-topography to less than decimetre (100 mm) accuracy even under vegetation cover. The structure of the vegetation cover can also be mapped. Digital multi-spectral imagery tools offer a way of mapping the health and vigor of vegetation and to assess changes over time. Specialised data such as thermal imaging, canopy mapping and shading models offer tools to monitor environmental functions and to track changes in the target area over time.

Remote assessment technology incorporated into UAV's is proving to be useful for smaller areas and is well suited to assessment of complex areas such as the riparian zone. It is also fast becoming very cost effective.

Figure 35 shows a high resolution image spanning sections C1 – C2 – C3 of Yakamia Creek that was photographed from an Unmanned Aerial Vehicle (UAV). The insert indicates the vastly improved level of aerial image resolution that can be obtained.

Figure 36 shows a Digital Elevation Model (DEM) of the same area emphasizing the canopy height of remnant vegetation and topography of the cleared area.

Figure 35: High resolution image spanning sections C1 – C2 – C3 of Yakamia Creek with insert showing the improved level of image resolution.

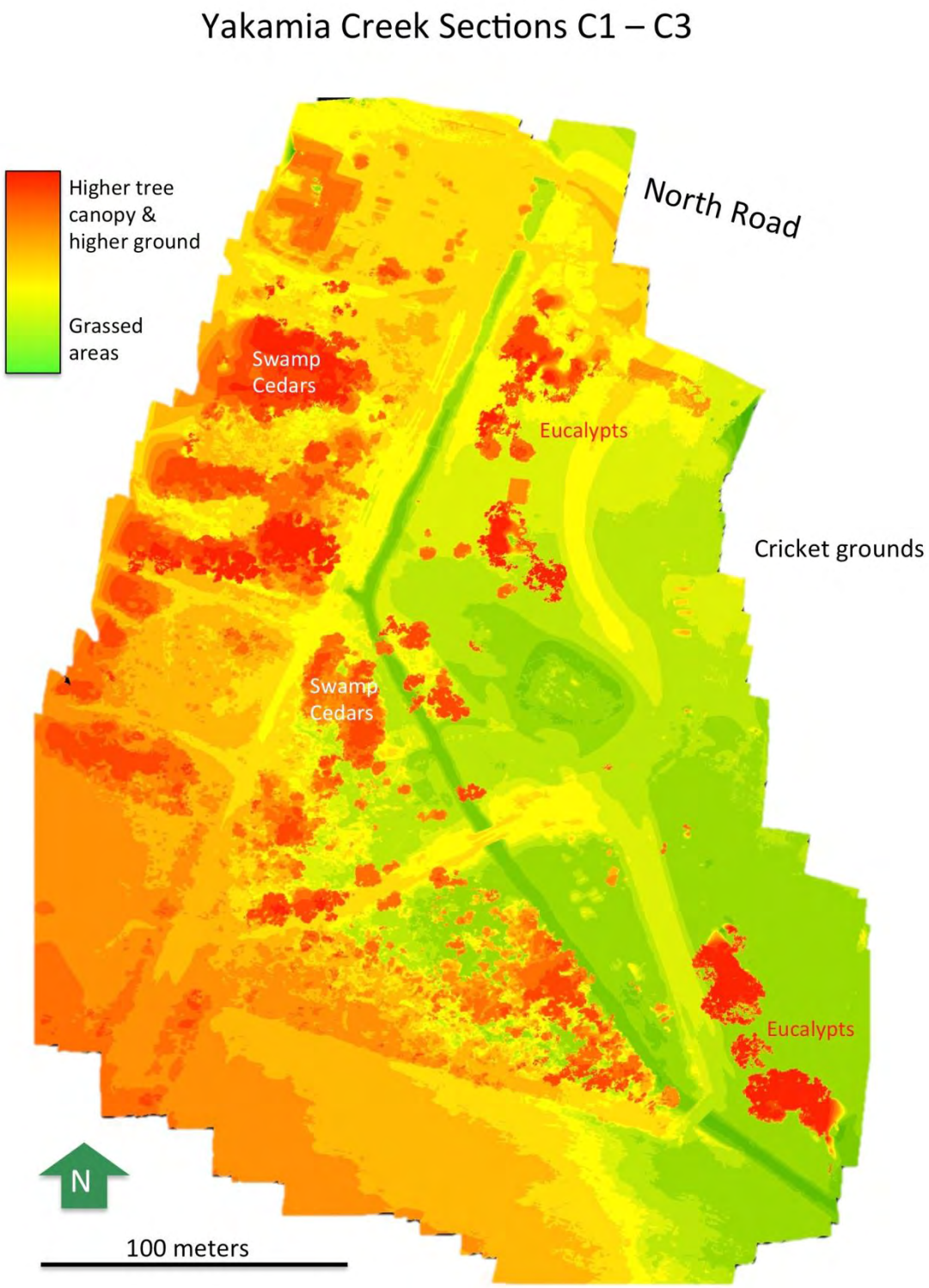

Figure 36: Digital Elevation Model (DEM) of sections C1 – C2 – C3 of Yakamia Creek emphasizing the canopy height of remnant vegetation and topography of the cleared area.