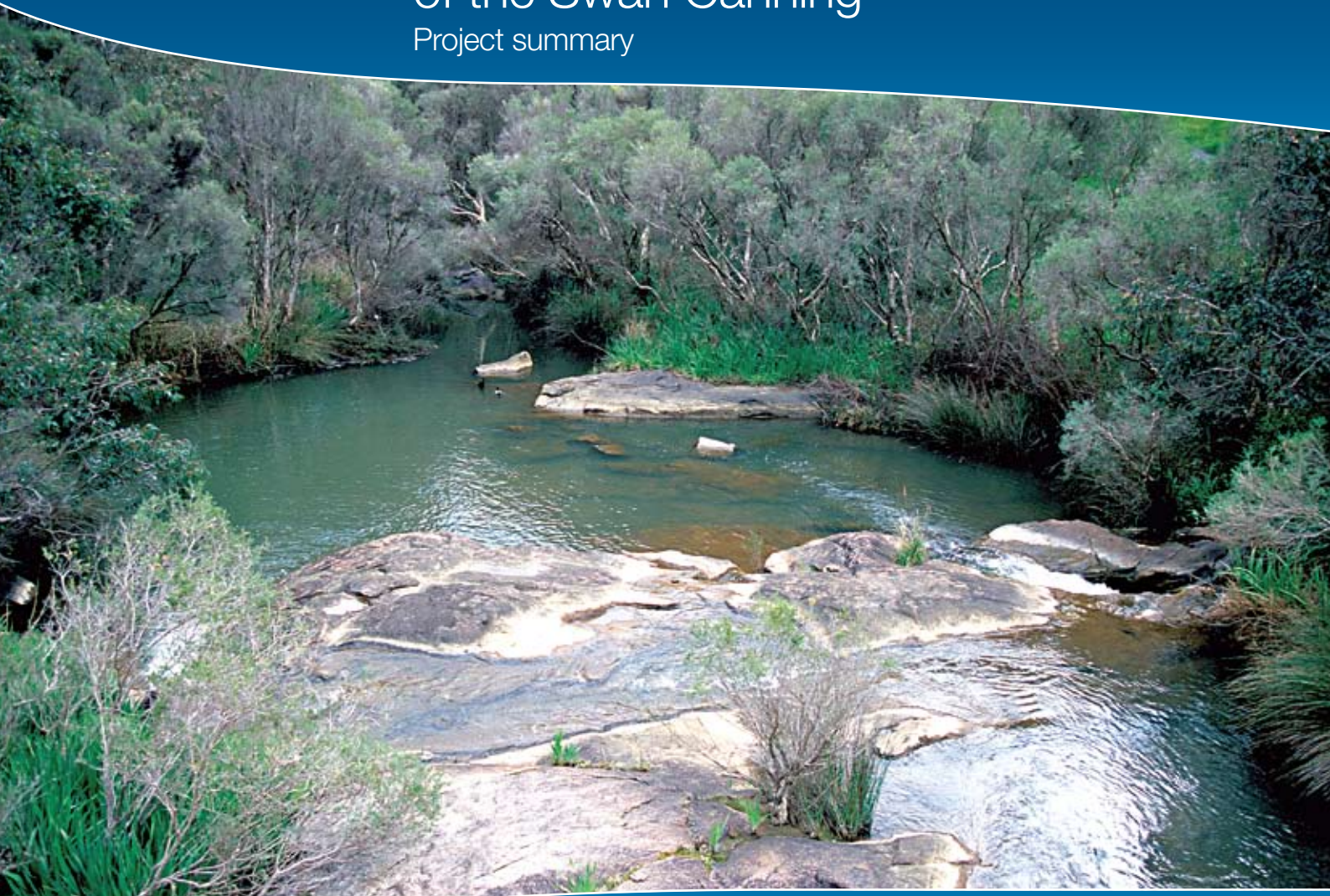
Government of **Western Australia**
Department of **Water**

River Health Assessment Scheme for the sub-catchments of the Swan Canning

Project summary



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May 2009

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Summary

The River Health Assessment Scheme (RHAS) was initiated in 2006 through funding from the then Swan Catchment Council (now Perth Region NRM) to develop and implement a river health assessment program for waterways in the Swan Canning catchment. The RHAS was designed to measure and report on the ecological health of both rivers and drains, with a view to developing resource condition targets in the future. The overall aim for the RHAS was the creation of a cost-effective, rapid assessment tool that has the capacity to detect long-term changes in river health.

Indicators for the RHAS were selected so that they reflected the organisation (biodiversity, species composition and food web structure), vigour (rates of production, nutrient concentrations) and resilience (ability to recover from disturbance) of aquatic ecosystems in the Swan Canning. Due to a lack of suitable reference sites and limited historical data (with the exception of water quality data), the effectiveness of selected indicators was assessed using existing guidelines, models of ecological health assessment developed for other geographical areas and expert opinion.

The RHAS was developed over a two-year period between 2006 and 2007, in two stages. Stage one focused on desktop studies and expert consultation to identify and select potential indicators and assessment techniques. This included a pilot study in 2006 to test the effectiveness of selected indicators in the Swan Canning catchment.

Stage two involved a more comprehensive assessment of river health at 20 sites using techniques refined during stage one. Data collected during stage two were used to derive and validate rating scores for each of the themes. Five themes encompassing 23 separate indicators were used to assess river health within the Swan Canning in 2007. These were: physical form, riparian vegetation, water quality and communities of both macroinvertebrates and fish/crayfish.

Other documents related to this report are the RHAS User's Manual (Galvin et al. 2009) and the river report cards (in preparation).

Key recommendations

The RHAS was primarily developed by the analysis and assessment of data from 20 sites collected in one sampling event. The scoring techniques are currently overly simplistic and further research (as more data becomes available) is required on a number of topics including:

- The best way to integrate the scores within each theme to calculate the overall theme score.
- The best way to integrate the theme scores to calculate the overall site score.
- The best way to aggregate site scores to calculate the overall sub-catchment score.
- Some of the scoring methodologies themselves also need further investigation to ensure they are robust and appropriate for the Swan Canning system.

- Whether streams should be split into categories. For example, should streams be categorised into upland (located on the Darling Scarp) and lowland (located on the coastal plain) streams to allow more robust scoring methodologies to be developed.
- The temporal and spatial variability in the themes and indicators and, from this;
  - the minimum number of sites required in a sub-catchment to enable a robust sub-catchment score to be calculated, and
  - the required sampling frequencies for each of the themes and indicators.
- As further research is conducted on the biology of south-west macroinvertebrates, fish and crayfish, this should be incorporated into the themes and used to help interpret the indicator and overall theme scores. In general, the biology of these faunal groups is poorly understood.
- As more data is collected, sensitivity analyses should be undertaken to determine whether there is redundancy in the indicators and/or themes used.

Physical form

As well as the overall recommendations given above, the following recommendation applies to the physical form theme:

- Based on current understanding, the physical form theme should be assessed every five years (unless there has been some dramatic change in physical form (i.e. due to flooding).

Riparian vegetation

As well as the overall recommendations given above, the following recommendations apply to the riparian vegetation theme.

- Based on current understanding, the riparian vegetation theme should be assessed every five years (unless there has been some dramatic change in physical form (i.e. due to fire or clearing).
- As more data is collected, the scoring protocols should be refined. Currently, they are heavily based on the ISC methodologies and they may require further adaptation to the Swan Canning system.
- Other options for assessment such as using aerial photography should be investigated. At present the riparian vegetation theme is time consuming in the field; so the use of aerial photography and satellite imagery may reduce the time spent assessing this theme and make it possible to assess the entire sub-catchment rather than just individual sites.

Water quality

As well as the overall recommendations given above, the following recommendations apply to the water quality theme.

- Based on current understanding, the water quality theme should be assessed monthly with the exception of diel DO and temperature, which is to be assessed annually in spring under baseflow conditions.
- As more data is collected, the scoring protocols should be refined, especially for diel DO and temperature.
- The concept of 'critical indicators' should be investigated. That is, where the value returned for a critical indicator is outside of the tolerances of native fauna then that indicator should receive a score of zero and this score should over-ride the overall water quality score. For example, if a pH value of 1 is recorded then the indicator score for pH will be zero and the overall water quality score should also become zero. Potential critical indicators are pH, diel DO, diel temperature and conductivity.

Macroinvertebrates

As well as the overall recommendations given above, the following recommendations apply to the macroinvertebrate theme.

- Based on current understanding, the macroinvertebrate theme should be assessed annually under baseflow conditions in spring.
- The construction of an AUSRIVAS model which uses a lower level of taxonomic resolution, perhaps targeting sensitive groups such as Odonata, Plecoptera and Trichoptera.
- Sort macroinvertebrate samples in the field using a box sub-sampler as described in Halse et al. (2002).
- Explore other methods of analysing the macroinvertebrate data, including incorporating functional feeding groups and community composition.
- Investigate the possibility of using indicator species.

Fish and crayfish

As well as the overall recommendations given above, the following recommendations apply to the fish and crayfish theme.

- Based on current understanding, the fish and crayfish theme should be assessed annually under baseflow conditions in spring.
- More research should be conducted to determine the appropriate sampling effort per site to adequately represent the fish and crayfish present.

1 Introduction

The River Health Assessment Scheme (RHAS) was initiated in 2006 through funding from the then Swan Catchment Council (now Perth Region NRM) to develop and implement a river health assessment program for waterways in the Swan Canning catchment. The RHAS was designed to measure and report on the ecological health of both rivers and drains, with a view to developing resource condition targets in the future. The overall aim for the RHAS was the creation of a cost-effective, rapid assessment tool that detects long-term changes in river health.

It is important to note that the RHAS was developed for systems within the Swan Canning catchment and will therefore require modification before use in other waterways. Further, the RHAS is designed to be used during spring baseflow conditions. It must not be used for scoring data collected at other times of the year (with the exception of water quality).

1.1 Background

Since European settlement, streams in the Swan Canning have been significantly modified through clearing and draining of low-lying areas to make land suitable for agriculture and urban development. Artificial drainage systems and altered natural streams now form an extensive drainage network. This has impacted stream health and ecology in numerous ways, including:

- straightening and deepening of streams
- removal of large woody debris
- replacing stream sections with concrete channels and pipes
- clearing of riparian vegetation and unrestricted grazing – causing erosion of stream beds and banks leading to sedimentation which smothers plants, animals and in-stream habitats
- input of nutrients, pesticides, hydrocarbons, heavy metals and other pollutants.

All of these changes have resulted in an overall decline in aquatic species, habitat diversity and water quality. Consequently, there has been an increase in the invasion of exotic flora and fauna species, putting further pressure on the existing native biota.

Anthropogenic impacts and degradation of streams is ongoing and in many cases growing in intensity due to increasing developmental pressure from an expanding population. Monitoring the health of our waterways is of utmost importance if we want to be able to target and assess management actions and also to assess whether systems are improving, degrading or stable. Figure 1 shows a conceptual diagram which captures some of the key differences between healthy and unhealthy rivers in the Swan Canning.

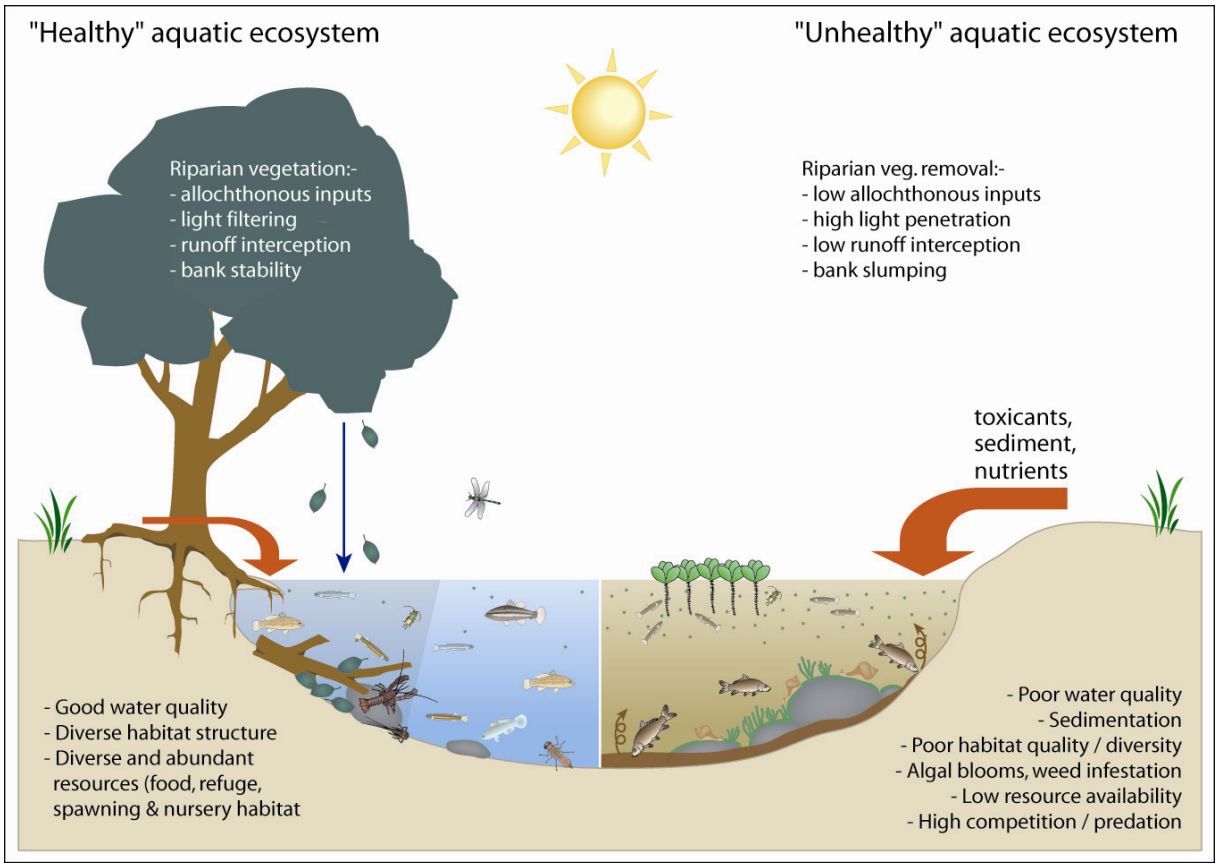

Figure 1 Conceptual diagram showing healthy and unhealthy aquatic ecosystems in the Swan Canning catchment

1.2 Defining river health

The term ‘river health’ is inherently ambiguous as it encompasses the natural variations in form and function existing between all river systems. Unfortunately, this makes scoring environmental conditions difficult – as what is healthy in terms of system dynamics in one system may not be true of another. The situation is further confused as river health is a value-laden term. Different sectors of the community will have different views on what a healthy river looks like depending on the values they hold. For example, defining river health for conserving biodiversity will be different from defining it for water supply or for recreation. Taking an ecological view, a healthy river may be described as an undisturbed river similar to that found in pre-European times.

For the purpose of the RHAS, river health is defined in terms of ecological integrity, targeting the broad themes that underpin function and stability of any system. The factors governing ecology, as described by Rapport et al. (1998) and Bunn and Davies (2000), include:

- organisation (biodiversity, species composition and food web structure)
- vigour (rates of production and nutrient cycling)
- resilience (ability to recover from disturbance).

Using this definition, a healthy river has the ability to support and maintain key ecological processes and a community of organisms with a species composition, diversity and functional organisation that is as similar as possible to that of an undisturbed ecosystem.

In order to appropriately assess the health of rivers in the Swan Canning catchment, an understanding of the attributes of a typical healthy river is needed so that the impacts of human activity can be determined.

2 Designing the River Health Assessment Scheme

2.1 Challenges and consideration

A wide range of river health assessment programs have been created, both nationally and internationally. These are based on system-specific models of function and form developed outside of the Swan Canning catchment so a direct transfer of these methods to the RHAS is not generally possible. As such, adaptations of techniques to reflect the specific factors governing the ecology of the Swan Canning systems were required.

One of the most complex challenges in characterising Western Australian rivers and streams is that they are unique in many ways from systems where existing assessment tools have been developed; for instance:

1 *Varied physical form:* Swan Canning waterways are generally much smaller and shallower than on the east coast of Australia (where most relevant Australian indicators have been developed) – thus the same level of complexity may not be supported.

2 *High degree of endemism:* individual species can vary significantly regarding their interactions with their environment (i.e. seasonal migration patterns). A sound understanding of each species is required to account for observed dynamics. Currently, our knowledge of aquatic flora and fauna of south-west Western Australia is limited.

3 *Paucity of species:* given the size of our river systems it is understandable that they would naturally support a more simplified trophic structure. Unfortunately, low species diversity causes an increased potential for error in any indicators that are based on measuring diversity.

4 *Presence of ephemeral rivers*: some streams in the Swan Canning system only flow during the wet months and dry up over summer. As this can greatly influence system characteristics (for instance, non-burrowing crayfish would not be expected), indicators need to be adaptable enough to assess the health of naturally ephemeral streams, streams with permanent flow and those becoming ephemeral due to anthropogenic reasons.

5 *Assessment of drains:* given the extensive drainage network that required assessment within the RHAS, river health indicators need to be designed to account for the significant differences in physical form and function of drains, compared to natural river systems.

The uniqueness of south-west Western Australian rivers means that almost all existing indices needed validation before use in the RHAS, and in some cases new indices were required. This situation was further complicated by a lack of suitable reference sites, sites considered to be in a pristine, or near-pristine, state (pre-European condition), that can be used to validate indicators and provide a

benchmark against which health in test sites can be assessed. Given that human settlement occurred in the late 1700s, our ideas of what should be classified as ‘pristine’ is ambiguous. This is particularly true of river systems located within or near urbanised centres. Other river health monitoring programs in Australia have overcome this issue by using minimally disturbed rivers that have had little influence rom human activities as reference sites. This approach is not ideal for the Swan Canning catchment given the lack of minimally impacted sites and the limited historical data available, particularly in relation to biological information.

The ways in which these challenges were faced when designing the RHAS for the Swan Canning is described in Sections 2.2 and 2.3.

2.2 Project schedule and objectives

The RHAS guidelines were developed over a two-year period (2006 and 2007), in two stages (Figure 2). Stage one focused on desktop studies and expert consultation to identify and refine potential indicators, followed by a ground-truthing exercise in 2006 to test their effectiveness in the Swan Canning catchment. Work carried out in stage one included:

1 Conducting a literature review of existing methodologies for river health assessment to derive a list of potential indicators. Indicators were chosen based on local knowledge and experience, scientific literature and other health/condition monitoring programs in Western Australia and other states. An extensive list of indicators was derived, including measurements of both the structural attributes (species composition, biodiversity, food web structure and water quality) and functional aspects (rates of primary production and respiration) of river ecosystems.

2 Holding a technical workshop with local experts in the field of river health assessment, as well as representatives from the Swan Canning sub-regional community groups. This workshop refined the list of potential indicators identified through the literature review and also discussed the overall approach to be taken for assessing river health in the Swan Canning catchment. The outcomes of this workshop were incorporated into Section 2.3.

3 Development of simple conceptual models which illustrate how healthy ecosystems function and how they might respond to human disturbance such as riparian loss, nutrient enrichment and erosion. These models enabled the identification of critical components in the ecosystem to target for monitoring.

4 Undertaking a pilot study, in October–November 2006, to determine which indicators were most successful in assessing river health in the Swan Canning sub-catchments. Six themes, encompassing 20 separate indicators were selected to be tested in the pilot study. These were physical form, riparian vegetation, water quality, macroinvertebrates, fish/crayfish and ecosystem processes. Indicators were assessed based on the ease and reliability of data collection and

how well they differentiated between various levels of disturbance. Those found to be ineffective were dropped.

Stage two involved a more comprehensive assessment of river health throughout sub-catchments of the Swan Canning, utilising techniques refined from stage one along with an increased spatial resolution. Only five themes were assessed in the 2007 program, as 'ecosystem processes' was removed in an effort to reduce total time for site assessments. The techniques and methodology for each of the indicators used are outlined in the River Health Assessment Scheme User's Manual (Galvin et al. 2009). Data collected were used to derive scoring systems for each indicator, discussed further in section 2.3.

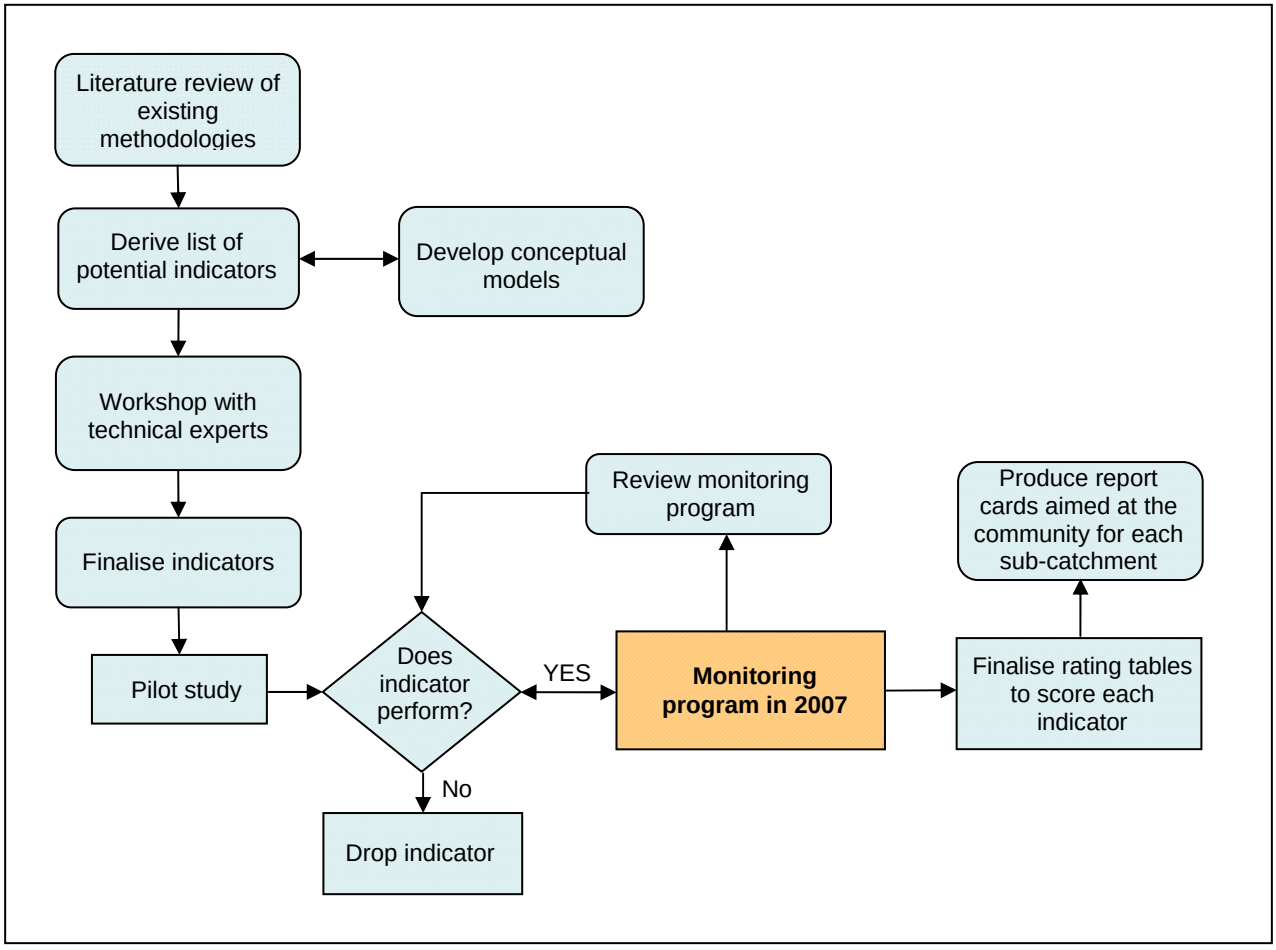

Figure 2 The process undertaken to develop the RHAS for the Swan Canning catchment

Results from the RHAS monitoring in 2007 will be presented in the form of community river report cards. The river reports are an illustrative way of presenting river health in each of the 12 sub-catchments sampled as part of the RHAS. They will provide the overall grade for the sub-catchment along with comments pertaining to each of the five themes used to calculate the grade.

2.3 Developing river health indicators for the Swan Canning system

The RHAS does not use the typical reference condition approach, as historical data (to determine pre-European condition) are limited and there are very few areas that would be suitable for use as reference sites, especially on the coastal plain. Instead the RHAS adopted a generic approach whereby reference condition was determined as what would be expected at sites with minimal or no disturbance using a combination of information from previous studies and expert opinion. This is termed synthetic reference condition (Costelloe & Ladson 2006).

For some indicators setting a synthetic reference condition value is straightforward; for example, no exotic fish species would be expected. For other indicators, such as canopy cover, it is harder to determine reference values. In these cases, values were chosen based on professional judgement and standard guidelines, such as ANZECC/ARMCANZ (2000).

The RHAS also adopted a benchmarking approach, where sites will be compared over time to show changes (trends) in the health of the stream. This approach has limitations for immediate implementation due to insufficient current data to form a baseline for the sub-catchments of the Swan Canning. The major gap in knowledge relates to biological data, with most current monitoring programs confined to physico-chemical water quality.

Twenty three indicators were chosen for inclusion in the final RHAS program, divided among five themes. Scores for each indicator are based on a five-category rating scale (ranging from zero to four), which has been shown to provide sufficient sensitivity to identify changes in condition. The scores for each indicator are combined to provide an overall score (out of 10) for each theme. Summing the scores of each theme produces an overall river health score out of 50. This scoring method was purposefully designed to allow easy adaptation following the addition of new data. For example, more data may indicate that weighting of individual themes or individual indicators may be required, as some indicators may be more important or sensitive than others.

In the current RHAS program no effort has been made to develop guidelines for different stream types, as is currently used in south-east Queensland's Ecological Health Monitoring Program (EHMP). The only exception is the diel water temperature range indicator, which adopted the guideline values from the south-east Queensland's EHMP as no other guidelines existed. Future modifications of the RHAS should look at developing separate guidelines for different stream types to account for variability among streams. For example, streams may be separated into upland (located on the Darling Scarp), lowland (on the coastal plain) and tannin-stained river systems.

2.4 Study area

The Swan Canning catchment has a Mediterranean climate (mild wet winters and hot dry summers), with the majority of rain falling between May and September. Long-term mean annual rainfall is between 800 and 1100 mm, with the highest rainfall occurring on the Darling Scarp. Stream flow varies greatly with season, with many streams being ephemeral, flowing during the winter and drying out in summer. Deepening of stream channels to assist with urban drainage has altered flow regimes allowing some streams to flow year round.

The Swan Canning catchment extends from the Ellen Brook sub-catchment (north of Muchea) to Armadale in the south, east to Mundaring, and west to Fremantle (Figure 3). It is comprised of 31 sub-catchments, ranging in size from Ellen Brook (~715 km^2) to Belmont central (~4 km^2), with a combined area of approximately 2110 km^2. For the purpose of the RHAS, the greater Avon catchment was not included.

Site selection for pilot study

Three rivers and one drain were included in the pilot study (Table 1). Two sites on Ellen Brook and one site on Southern River were chosen to represent sub-catchments disturbed as a result of land clearing for agriculture and urban development. In the absence of reference sites within the Swan Canning catchment, one site at 31 Mile Creek (located just outside the Swan Canning catchment boundary) was chosen as it is located within a minimally disturbed forest (drinking water catchment). Mills Street Main Drain was included to represent drains in the Swan Canning catchment.

Table 1 The four sub-catchments assessed in the 2006 pilot study, their approximate areas, dominant land use and number of sites

Sub-catchment	Area (km^2)	Dominant Land use	Number of sites
Ellen Brook	715	Rural: agricultural, broad-acre grazing, animal feedlots, horticulture and viticulture	2
Southern/Wungong River	148	Rural: broad-acre agriculture, horticulture, poultry. Urban – low-density residential	1
Mills St Main Drain	12	Urban: commercial, high-density residential	1
31 Mile Creek	11	Forested, drinking water catchment	1

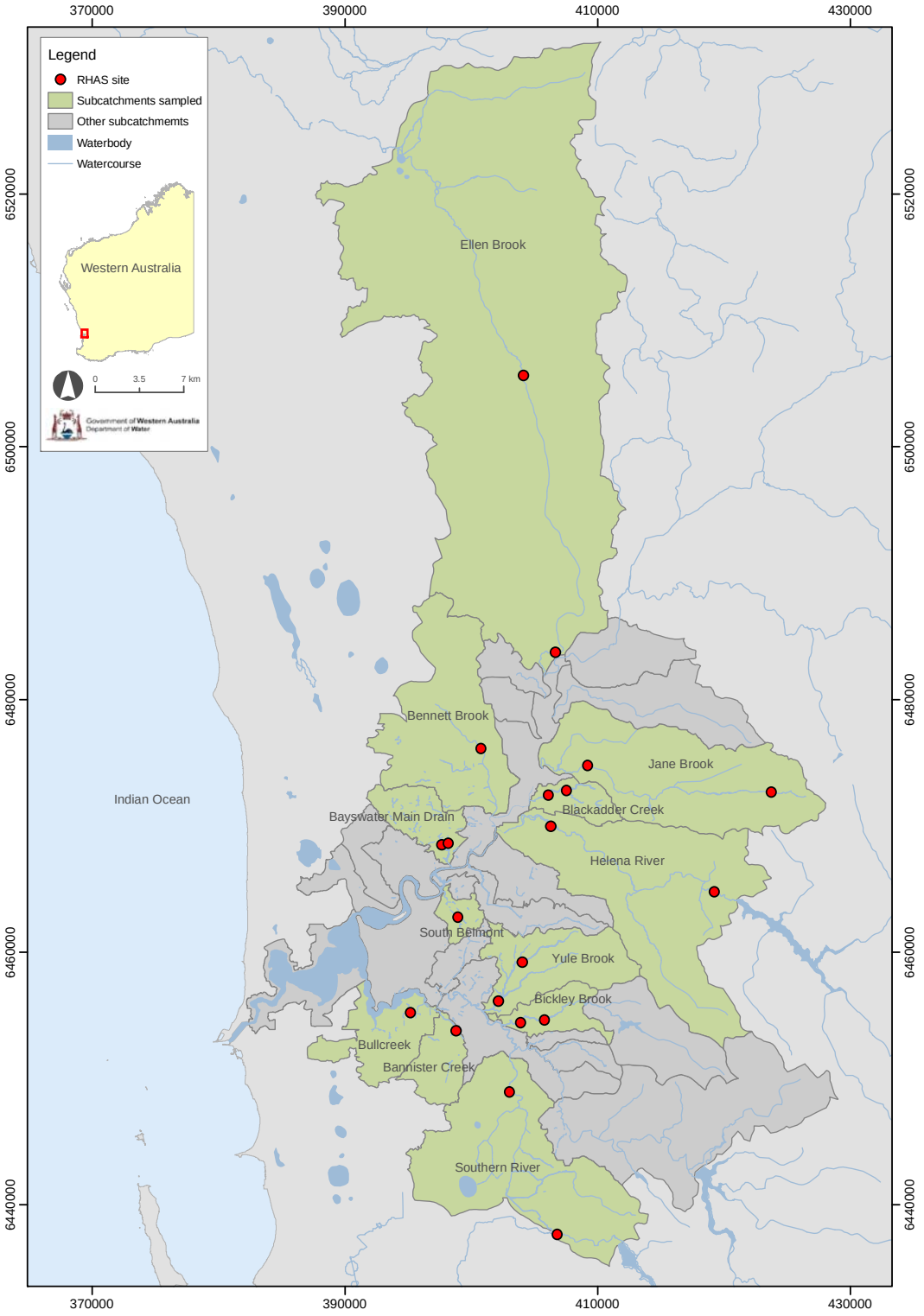

Figure 3 Swan Canning sub-catchments showing sites assessed in 2007

Site selection for 2007 major study

The major field trial was undertaken between October and November 2007 at 20 sites across 12 sub-catchments (Figure 3). Assessment techniques were refined from the pilot study and a greater number of sites were included in order to cover a variety of land uses and disturbances.

Sites were chosen according to the dominant land uses within the Swan Canning sub-catchments (Table 2). This allowed the effect of different land uses on the chosen indicators to be tested. Two sites were chosen in minimally disturbed areas located on the Darling Scarp (Helena River and Jane Brook). Six sites were chosen in rural to semi-rural, agricultural areas on the coastal plain (Southern River, Ellen Brook, Jane Brook, Helena River and Wungong River) and a total of 12 sites were located in urbanised areas on the coastal plain (Bayswater Main Drain, Yule Brook, Woodlupine Brook, Bickley Brook, Bannister Creek, Bennett Brook, South Belmont Main Drain, Bullcreek, Blackadder Creek and Woodbridge Creek).

Table 2 Sub-catchments assessed in the 2007 major field trial, their approximate areas, dominant land use and number of sites assessed.

Sub-catchment	Area (km^2)	Dominant Land use in catchment	Number of sites
Ellen Brook	715	Rural: agricultural, broad-acre grazing, animal feedlots, horticulture and viticulture	2
Jane Brook	138	Rural, large tracts of native forest (water-supply area), some small areas of viticulture and poultry farming	2
Helena River	176	Urban/rural: low-density residential, mixed light and service industries. Recreational/conservation reserves	2
Bennett Brook	112	Urban/semi-rural: low-density residential, livestock feedlots, viticulture and horticulture	1
South Belmont Main Drain	10	Urban, light service industries and high-density residential	1
Bayswater Main Drain	27	Urban: high-density residential (sewered and unsewered); commercial, areas of light industry	2
Blackadder/Woodbridge Creek	17	Urban: medium-density residential; service industries and business zones	2
Southern/Wungong River	149	Rural: broad-acre agriculture, horticulture and poultry. Urban: low-density residential	2
Yule/Woodlupine Brook	55	Rural: horticulture and poultry. Urban, extensive areas of light to medium industry and large tracts of parklands	2
Bickley Brook	21	Urban, residential and industrial	2
Bullcreek	42	Urban: high density residential	1
Bannister Creek	23	Urban, commercial, light and heavy industry	1

Typically, two sites were chosen per sub-catchment. These sites were chosen primarily to represent the main land uses in the sub-catchment as well as the extent and condition of the riparian vegetation. As the RHAS was to assess both natural and artificial watercourses (drains), consideration had to be given to those sub-catchments that contained closed pipe drains. The decision was made that closed pipe drains had no ecological value and any sub-catchment which contained greater than 70 per cent closed pipe drains (assessed based on the length of closed pipe drains compared to the overall stream and drain length for the sub-catchment) had an arbitrary classification of ‘very poor’ assigned to what would have been the second site. If more than two sites were to be sampled per sub-catchment that contained greater than 70 per cent closed pipe drains, then it may become necessary to assign more than one site an arbitrary classification of ‘very poor’ when calculating the overall sub-catchment health. It should be made explicit that the rating applied to the closed pipe drain will impact only on the overall sub-catchment score, not on the scores of any other sites assessed within the sub-catchment.

3 Themes and indicators

In order to assess river health appropriately, sufficient information is required to characterise the principal elements that govern ecological function: vigour, organisation and resilience (as explained in section 1.2). For the RHAS, this required capturing both the diverse range of conditions represented across the waterways (including drains) of the Swan Canning catchment and ensuring that techniques were appropriate for use within a rapid-assessment tool.

Five themes encompassing 23 indicators were selected for use in the RHAS, focusing on assessment of physical form, riparian vegetation, water quality and communities of both macroinvertebrates and fish/crayfish. Although hydrology is often included in river health assessment strategies (for example, the National Land and Water Resources Audit, the Sustainable Rivers Audit and the Index of Stream Condition (ISC) (Ladson & White 1999, White & Ladson 1999), due to a lack of data and limited resources and time it was not included in the indicator suite for RHAS.

The themes chosen for RHAS, along with the component indicators, are described below.

3.1 Physical form

The physical form theme assesses the physical condition of the river channel and the in-stream habitat which reflects both the complexity and the stability of the aquatic system. This is an indicator of the capacity to support healthy faunal communities, as there are direct relationships between niche availability and diversity and faunal complexity (Maddock 1999 and Calow & Petts 1994). Five indicators were chosen to assess the separate components of physical form: bank condition; bed stability; channel pattern; large woody debris and artificial barriers to fish migration. Further contextual information is also collected for: bank shape; bank slope; channel shape; stabilisation works; livestock access and channel modifications.

Indicators chosen for the physical form assessment were adapted from the ISC developed by Department of Sustainability and Environment for rural rivers and creeks (White & Ladson 1999 and Ladson & White 1999) with the addition of the channel pattern indicator, which was included to account for the urban drains that are present in the Swan Canning system.

Bank condition and bed stability

The bank condition and bed stability indicators were included in the RHAS to determine the amount of erosion, slumping, scouring and sedimentation occurring in a stream. Assessing the extent of erosion and bed instabilities can provide an indication of the degree of change from the inferred natural condition. Erosion and slumping of banks can contribute silt and sediment to the stream, which potentially has numerous deleterious effects on river health such as benthic habitat loss through sedimentation, reduced light intensity, smothering plants, reducing abundance and

taxa diversity of benthic macroinvertebrates and clogging the gills of fish (Boulton & Brock 1999).

Erosion can occur naturally in undisturbed streams but is typically more common and more severe in streams that have been modified/disturbed; for example, erosion is common in agricultural and urban areas where riparian vegetation and/or large woody debris has been removed to increase the flow carrying capacity in response to higher water tables.

Channel pattern

Channel pattern was included in the RHAS to evaluate the meanders or sinuosity of the stream. Meanders are an important feature of streams, providing greater habitat diversity (fast flowing sections, eddies and pools) and enabling the stream ecology to better handle storm surges by baffling and reducing the erosive nature of the flow. Many streams in the Swan Canning catchment have been altered to increase their flow capacities to provide drainage in urban and rural areas. Straightening of the streams, removal of woody debris and, in some cases, the replacement of stream sections with concrete channels and pipes can result in the decline and sometimes loss of many aquatic fauna species due to a direct reduction in habitat complexity or associated increases in competition/predation pressure. These types of modified streams also tend to favour exotic faunal species.

Large woody debris

The abundance of in-stream large woody debris was included in the RHAS following studies in Australian streams, which highlighted the ecological importance of woody debris as habitat for fish and macroinvertebrates (Lloyd et al*.* 1991, O'Connor 1992 and Gippel et al. 1996). Large woody debris can provide shelter from high flow velocities, shade, feeding sites (and food), spawning sites, nursery areas for larvae and juvenile fish, territory markers and refuge from predation. It can also help retain organic matter and hence provide areas for carbon and nutrient processing by microbes (Treadwell 1999).

Identification of the origin of large woody debris is important. The introduction of exotic tree and shrub species to riparian zones has resulted in a supply of non-native large woody debris. Native wood is thought to be more valuable to the stream ecosystem as it provides a more suitable substrate for macroinvertebrates and microbes due to its slow decay, stability and palatability (Penn 1999). McKie and Cranston (2001) demonstrated that the species of large woody debris could influence the composition and structure of macroinvertebrate assemblages in aquatic environments. For example, gougers (wood eating macroinvertebrates) preferentially colonised native Eucalyptus wood in preference to exotic species.

Historically, many of the rivers on the Swan coastal plain have been de-snagged. Accurate measures of large woody debris are difficult and time consuming. Gippel et al. (1996) used a line transect method to accurately assess the density of woody debris in streams; however, this method is time consuming and expensive and hence not suitable for a rapid assessment program such as the RHAS. To combat this,

visual assessments of the density of large woody debris (as was used to target a similar problem within the ISC (Ladson & White 1999)) were adopted.

Impact of artificial barriers on fish migration

The impact of artificial barriers on fish migration indicator was included as blocked fish migrations are believed to be one of main causes of the decline of freshwater native fish in Australia (Fairfull & Witheridge 2003, Harris & Gehrke 1997 and Mallen-Cooper 1993).

Barriers such as dam walls, weirs, culverts and waterway crossings can have a negative impact on native fish by creating physical, hydrological or behavioural barriers that can:

- interrupt spawning or seasonal migrations
- restrict access to preferred habitats, drought refuge areas and available food resources
- create isolated populations and reduced genetic flow between populations
- cause fish to congregate below a barrier increasing their susceptibility to predation and disease
- fragment previously continuous communities
- cause the extinction of upstream or downstream migrating species
- alter species diversity because of the local disappearance of some species and changes to the abundance of remaining species.

Three native species of the south-west (western minnow, western pygmy perch and nightfish) are reported to move upstream for pre-spawning migrations (Pen & Potter 1990, 1991a and 1991b), with similar expectations for the remaining species (undetermined at present due to lack of study). The presence of barriers is likely to interfere with migration of these native species, although little work has been undertaken in Western Australia in identifying potential barriers and their effects on migration of native fish. Morgan and Beatty (2003) have demonstrated that in-stream barriers in Bancell Brook (a concrete lip located below the slot boards) impeded the migration of pygmy perch, nightfish and western minnow.

The obstruction of fish passage can affect the long-term survival of many native fish species. The information collected by the RHAS is therefore valuable in providing background data on the distribution of native fish in urban waterways and the location of potential barriers.

Contextual information

The contextual information collected is not used in producing the overall RHAS score. It does, however, provide valuable information which can be used to help interpret the scores obtained.

The indicators used in the RHAS assessment were able to capture the required information to gauge the condition of physical form.

Recommendations

- Based on current understanding, the physical form theme should be assessed every five years (unless there has been some dramatic change in physical form (i.e. due to flooding).
- Further investigation be carried out on the temporal and spatial variability in the physical form theme and, from this:
  - the minimum number of sites required in a sub-catchment to enable a robust sub-catchment score to be calculated
  - the required sampling frequency for the theme to be determined.
- As more data is collected, the best way to integrate the indicator scores to derive the overall theme score can be determined.
- As more data is collected, a sensitivity analysis should be undertaken to determine whether there is redundancy in the indicators used.
- As further research is conducted on the biology of south-west macroinvertebrates, fish and crayfish this should be incorporated into the theme and used to help interpret the indicator and overall theme score. In general, the biology of these faunal groups is poorly understood.

3.2 Riparian vegetation

The riparian vegetation theme for the RHAS was developed by reviewing assessment methodologies used in Western Australia and other states. Foreshore condition assessments have been developed for rural (Penn & Scott 1995) and semi-rural/urban (Water and Rivers Commission 1999) streams in Western Australia. Methodologies used in other states include the ISC developed by Department of Sustainability and Environment for assessing rural rivers and creeks in Victoria (White & Ladson 1999 and Ladson & White 1999) and the Rapid Appraisal of Riparian Condition which has been developed to assess streams in south-eastern Australia (Jansen et al. 2005), tropics of Northern Australia (Dixon et al. 2006) and the mid-north of South Australia (Jansen et al. 2006). The RHAS has incorporated the methodologies from the four assessments above and has adapted them to Swan Canning conditions. However, most of the indicators assessed and scored in the RHAS were adopted directly from the ISC.

The riparian zone is the interface between streams and their terrestrial ecosystems and plays a critical role in maintaining healthy waterways through its ability to buffer potentially harmful inputs from the terrestrial environment. Riparian vegetation naturally supports high levels of biodiversity, providing shelter and food for both terrestrial and aquatic organisms, along with stream shading, breeding habitat, erosion protection and buffering from runoff and any associated contaminants. Extensive areas of riparian vegetation have been severely modified within the Swan Canning catchment as a result of urbanisation and agricultural activities (Pen & Majer 1993).

The intention of the RHAS was to develop and implement a simple and rapid method to assess the health of riparian vegetation in terms of quality (structural intactness and percentage cover and recruitment of native species) and quantity (width and continuity). It was not the intent to provide a detailed assessment of composition and community structure (for example: species richness, seedling/vegetative recruitment of key (dominant cover) native species, mortality of tagged individuals etc.). While this information would be useful in the conservation and management of the flora in the riparian zone, it requires a much larger effort and samplers will need to have a thorough knowledge of flora taxonomy; as such it is not suited to a rapid assessment program such as the RHAS.

Indicators for the RHAS were chosen to reflect the functional aspects of the riparian zone, such as: shading, retaining nutrients and sediment, providing a source of debris (logs, twigs, leaves) and contributing to bank stability. Indicators were chosen to assess the vegetation width, canopy cover, longitudinal continuity, structural intactness, cover of exotic vegetation, recruitment of native woody vegetation and leaf litter percentage cover. Further contextual information is also collected on bankfull and baseflow width and debris.

Vegetation width

The riparian width indicator is included in the RHAS as it is simple to measure and is indicative of the extent of degradation to a stream ecosystem. The width of the riparian zone provides an indication of buffering capacity and, typically, a direct relationship exists with external pressures such as cleared land, farming, industry and urbanisation. A similar relationship exists between vegetation width and the amount of riparian zone available for food, shelter and refuge for terrestrial animals.

Canopy cover

Canopy cover has been included due to its effect on light intensity and water temperature, both of which impact on the in-stream ecosystem. This indicator provides important information on the intactness of the canopy cover and the amount of in-stream shading provided at assessed sites.

Longitudinal continuity

The longitudinal continuity indicator measures the intactness of the riparian zone along the stream. Gaps in riparian vegetation can act as potential barriers to the movement of terrestrial fauna. They may also cause a reduction in suitable habitat and food supply as well as increasing vulnerability to competition and predation. Gaps can also increase physical and ecological disturbance to the riparian zone through erosion, sedimentation or runoff and allow for easy invasion by weed species. Lastly, gaps in riparian vegetation lead to an increase in stream temperatures due to a reduction in shading.

Structural intactness

The structural intactness indicator is included to provide information on the extent that the structural layers have been modified from pre-European condition. This

indicator assesses the density of cover for each of the main structural layers (ground cover, shrubs and trees) and compares it to pre-European density. A general knowledge of the original vegetation structure is required to assess this indicator so, where this is not available, the indicator may be difficult to assess.

Cover of exotic vegetation

The cover of exotic vegetation is included in the RHAS as it provides a good indication of the level of disturbance of the riparian vegetation. Disturbed sites are more prone to invasion by exotic species, which are better able to take advantage of opportunities for growth than their native counterparts. Exotic species generally grow quickly after a disturbance such as fire (e.g. veldt grass) or clearing (woody shrubs and long grasses). The presence of exotic plants can have a negative impact on the riparian zone by:

- displacing native plants due to direct competition for light, water and nutrients
- increasing fire fuel loads (grass)
- reducing native plant biodiversity
- reducing habitat for native animals
- inhibiting the natural processes necessary for riparian health.

The presence of exotics can also have a more direct effect on the aquatic environment: for example, exotics with deciduous leaves (i.e. willows), drop all their leaves in autumn (most natives lose leaves year round) resulting in an increased organic load to the stream. Their leaves decay quickly, which results in oxygen depletion that may affect fish and invertebrates and reduce water quality.

Recruitment of native woody vegetation

Recruitment of indigenous woody vegetation assesses the long-term viability of the riparian vegetation. Modification of the riparian vegetation due to weed invasion, stock grazing, predation by insects and other animals can affect the extent of recruitment and regeneration of native species. This indicator assesses the level of recruitment in the riparian zone and applies only to woody vegetation due to difficulties in assessing recruitment of groundcover species.

Contextual information

The contextual information collected is not used in producing the overall RHAS score. It does, however, provide valuable information which can be used to help interpret the scores obtained.

The indicators used in the RHAS assessment were able to capture the required information to gauge the condition of the riparian vegetation.

Recommendations

- Based on current understanding, the riparian vegetation theme should be assessed every five years (unless there has been some dramatic change in physical form (i.e. due to fire or clearing).
- Further investigation to be carried out on the temporal and spatial variability in the riparian vegetation theme and, from this:
  - the minimum number of sites required in a sub-catchment to enable a robust sub-catchment score to be calculated
  - the required sampling frequency for the theme to be determined.
- As more data is collected, the scoring protocols should be refined. Currently they are heavily based on the ISC methodologies and they may require further adaptation to the Swan Canning system.
- As more data is collected the best way to integrate the indicator scores to derive the overall theme score can be determined.
- As more data is collected, a sensitivity analysis should be undertaken to determine whether there is redundancy in the indicators used.
- Other options for assessment such as using aerial photography should be investigated. At present the riparian vegetation theme is time consuming in the field, so the use of aerial photography and satellite imagery may reduce the time spent assessing this theme.
- As further research is conducted on the biology of south-west macroinvertebrates, fish and crayfish this should be incorporated into the theme and used to help interpret the indicator and overall theme score. In general, the biology of these faunal groups is poorly understood.

3.3 Water quality

The physico-chemical indicators used to assess water quality in the RHAS were selected because they are known to have ecological importance in aquatic systems and are commonly included in other river health assessment programs like the ISC and EHMP.

Water quality is a valuable indicator, being both a direct indicator of health and an interpretative tool for explaining other indicator scores. Physico-chemical indicators are also relatively quick and cheap to assess. Indicators included in the RHAS are pH, conductivity, total nitrogen, total phosphorus, turbidity, diel dissolved oxygen and diel temperature range. Further samples are analysed for dissolved organic nitrogen, ammonium nitrogen, nitrogen oxides, soluble reactive phosphorus, true colour and alkalinity. These provide added contextual information.

pH

The pH of a water body reflects the concentration of hydrogen (H^+) and hydroxide ions (OH^-) in a water sample (Boulton & Brock 1999). The pH of fresh water systems tends to range between 6.5 and 8.0, although variations can occur due to catchment geology (Boulton & Brock 1999).

Most aquatic organisms and microbial processes have a preferred pH range and if this range is breached it may affect the physiological functioning (i.e. enzymes and membrane processes) of organisms (Boulton & Brock 1999 and ANZECC & ARMCANZ 2000). Changes in pH outside the normal range of a water body will cause sensitive species to die, while extremely high or low pH will kill all aquatic life. Reviews have indicated that a pH between 5 and 9 has no acute lethal effects on fish (ANZECC & ARMCANZ 2000); however, some pollutants such as ammonia and cyanide can become toxic within this range. Low pH can indirectly affect aquatic biota through the release of toxic metals (e.g. aluminium) from stream sediments. In addition pH can also determine the solubility and bioavailability of nutrients (phosphorus, nitrogen and carbon) to aquatic organisms (Boulton & Brock 1999).

Scoring is currently based on the rating scale developed for the ISC (Ladson and White, 1999).

Conductivity

Conductivity is the measure of the ability of water to conduct an electrical charge and can be used as a surrogate measure of salinity. Conductivity will vary naturally due to changes in stream flow and is typically lowest during high flows in winter, increasing as flow slows and stream levels drop due to evaporation in summer. Changes in conductivity can result from human activities such as land clearing, industrial and agricultural effluent, stormwater runoff and sewage effluent flowing into the stream.

Elevated salinity levels can cause deleterious effects on the physiology, biochemistry and behaviour of freshwater macroinvertebrates and fish (Kay et al. 2001 and Hart et al. 1991) and most aquatic organisms function optimally only within a narrow salinity range (ANZECC & ARMCANZ 2000). Although there is little information available on the sensitivities of Australian freshwater biota to increasing salinity Hart et al. (1991) concluded that salinity concentrations above 1000 mg/L would cause adverse effects. It is unclear whether many south-west freshwater species of macroinvertebrates have a high salinity tolerance or that sensitive taxa have already been lost (Halse et al. 2003).

Scoring was adapted from the categories used for the Statewide River Water Quality Assessment (Department of Water, 2004) which used ANZECC/ARMCANZ (2000) guidelines and expert opinion to set the categories.

Nitrogen and phosphorus

Nitrogen and phosphorus are essential elements for the growth and survival of both plants and animals. Total nitrogen and total phosphorus are a measure of all forms of nitrogen and phosphorus present in the stream. While some forms of nutrients are

more readily bioavailable than others, measuring the total nutrient concentrations gives an indication of the total pool of nutrients that is potentially available for uptake.

Nitrogen naturally enters waterways either from the breakdown of dead organic matter, by being transported by groundwater or via atmospheric nitrogen gas fixation by specially adapted plants. High levels of dissolved forms of nitrogen (nitrate, nitrite, ammonium and dissolved organic nitrogen (such as urea) can be toxic to many aquatic organisms. Anthropogenic sources of nitrogen include fertilisers, animal droppings, combustion of fossil fuels, septic tanks and exotic plant debris.

Phosphorus naturally enters waterways either from the breakdown of dead organic matter or via the gradual weathering and leaching of rocks and soils in the catchment. Elevated phosphorus levels in rivers are typically associated with pollution from fertilisers, detergents, industrial waste and plant and animal wastes.

Nutrient enrichment stimulates plant and algal growth and can result in prolific plant and epiphyte growth and/or algal blooms. This can lead to large diel oxygen fluctuations as oxygen is produced during the day by photosynthesis and consumed at night via respiration. Further, decomposition of plants and algae can result in rapid oxygen consumption, which may lead to anoxic or hypoxic events. Low dissolved oxygen concentrations (and toxic algae) can harm macroinvertebrates, fish and other organisms.

Total nitrogen and phosphorus concentrations are included in the RHAS as they provide an indication of the level of nutrient enrichment in a stream and hence can indicate how susceptible it is to nuisance algal and macrophyte growth and associated low oxygen levels.

Dissolved nutrient fractions (ammonia, nitrogen oxides, dissolved organic nitrogen and soluble reactive phosphorus) are also measured to give contextual information to the water quality theme. The form in which a nutrient is present can give some indication as to its source (though this is an indication only, as in-stream nutrient cycling can change the form of nutrients by the time they are sampled).

Scoring was adapted from the categories used for the Statewide River Water Quality Assessment (Department of Water, 2004), which used ANZECC/ARMCANZ (2000) guidelines and expert opinion to set the categories.

Turbidity

Turbidity is a measure of the clarity or cloudiness of water and provides an indirect indication of light penetration (Boulton & Brock 1999). Turbidity levels are related to the amount, size and composition of suspended and colloidal material such as clay, silt, phytoplankton, colour and other microscopic particles present.

Turbidity can be generated from human activities such as clearing of vegetation (particularly riparian zones), runoff from urban areas, extractive industries such as mining and increased soil erosion (Boulton & Brock 1999). Turbidity can also arise from deposited sediment which has been re-suspended due to high flows or other factors such as exotic fish (both carp (*Cyprinus carpio*) (Koehn 2004) and gold fish

(*Carassius auratus*) (Richardson et al. 1995) increase turbidity levels due to foraging through sediment looking for food).

While in suspension, turbidity reduces light penetration resulting in reduced primary productivity and may also clog the feeding apparatus of filter-feeders (Metzeling et al. 1995 and Wood & Armitage 1997). In fish, it can clog gills, smother food and eggs and reduce the efficiency of predation in those species that rely on sight to detect their prey (Metzeling et al. 1995 and Wood & Armitage 1997). As it settles, suspended material causes infilling of interstitial spaces, reducing the habitat available for benthic animals (Campbell & Doeg 1989) and also smothers benthic animals and submerged plants (Boulton & Brock 1999).

Further, suspended material increases water temperature by absorbing heat from the sun. This decreases the amount of dissolved oxygen present (cool water holds more oxygen than warm). Suspended material also provides a transport mechanism for nitrogen, phosphorus, toxic heavy metals and other contaminants in the stream.

Scoring was adapted from the categories used for the Statewide River Water Quality Assessment (Department of Water, 2004) which used ANZECC/ARMCANZ (2000) guidelines and expert opinion to set the categories.

Diel dissolved oxygen

Dissolved oxygen (DO) is a measure of the amount of gaseous oxygen (O_2) dissolved in water. DO concentrations affect the distribution, behaviour and physiological activity of aquatic animals with lethal effects observed at both low and very high concentrations. Decreases in DO can be caused by the respiration of plants, animals and by chemical and bacterial processing of organic matter in the water and sediments. DO solubility depends on temperature, decreasing as temperature increases. Therefore, DO can fluctuate over a 24-hour period, especially in highly disturbed systems. Large diel DO ranges are typically associated with highly productive systems and place pressure on ecological function, potentially leading to fish and invertebrate mortality.

Oxygen requirements and tolerance ranges of fish and macroinvertebrates can vary substantially with the type of species (especially between warm-water and cold-water biota), life stages (eggs, larvae and adults) and with different life processes (feeding, growth and reproduction) (ANZECC & ARMCANZ, 2000). DO concentrations below 5 mg/L are likely to have deleterious effects on aquatic macroinvertebrates and fish (ANZECC & ARMCANZ, 2000).

The RHAS included the measurement of diel DO. To assign scores to the diel DO indicator, the ANZECC and ARMCANZ (2000) guideline of 6 mg/L or greater was used as a threshold, above which it was assumed that there was adequate DO present. The lower threshold was set at 2 mg/L, as below this concentration most native faunal species will experience mortality. Between 2 and 6 mg/L was broken into three bands, resulting in a total of six categories, each of which carries a different score.

Currently no upper limit has been developed for DO concentrations due to a lack of local reference data and suitable guidelines. An upper limit may be included in the future when more data are collected and the effects of high DO concentrations on native fish and macroinvertebrates are better understood. The current guidelines for DO are based on limited data and therefore banding levels and the concentration thresholds (above 6 mg/L and below 2 mg/L) may change when more data are collected in the future.

Diel water temperature

Water temperature is a valuable indicator of stream health because it can affect both the ecosystem functioning (ecosystem metabolism) and community structure of aquatic organisms. It is also one of the drivers of DO concentrations in water (warm water being unable to hold as much dissolved oxygen as cooler water).

Fish and aquatic invertebrate communities are very sensitive to temperature changes, with many enzymes becoming denatured at high temperatures. All aquatic animals have preferential temperature ranges in which they can reproduce effectively and survive. Large temperature changes (increases or decreases) over a short period can affect organisms' growth, metabolism, reproduction, mobility and migration, which can lead to reduced biodiversity (ANZECC & ARMCANZ, 2000).

Water temperature changes occur naturally as part of daily and seasonal cycles but may be exacerbated by human activities. Riparian clearing can lead to significant increases in daytime water temperature and larger diel and seasonal temperature ranges. This was clearly demonstrated in the 2007 RHAS field trial where all drains and some streams with little or no riparian vegetation had temperature fluctuations greater than 4°C over a 24-hour period.

Diel water temperature was measured in the RHAS. In the absence of referential data for the Swan Canning catchments, the scoring protocol used as part of the south-east Queensland EHMP for diel temperature was used. The EHMP has set guidelines for diel temperature range based on stream type (lowland, upland and coastal wallum streams) (South East Queensland Healthy Waterways Partnership 2006). These guidelines will be used in the interim until further data can be collected to develop Swan Canning specific scoring.

Temperature (and DO) in streams varies depending on the depth and position in a stream (full sun, part shade or full shade). Water at depth in pools may be a lot cooler than surface waters as a result of stratification. Deep pools can therefore act as refuge areas for aquatic animals to escape warm surface waters. To help account for this variability, the loggers were always deployed at the same depth. This does mean that any potential refuges were not considered when scoring.

Recommendations

- Based on current understanding, the water quality theme should be assessed monthly with the exception of diel DO and temperature, which can be assessed annually in spring under baseflow conditions.
- Further investigation to be carried out on the temporal and spatial variability in the water quality theme and, from this:
  - the minimum number of sites required in a sub-catchment to enable a robust sub-catchment score to be calculated
  - the required sampling frequency for the theme to be determined.
- As more data is collected, the scoring protocols should be refined, especially for diel DO and temperature.
- The concept of 'critical indicators' should be investigated. That is, where the value returned for a critical indicator is outside the tolerances of native fauna then that indicator should receive a score of zero and this score should over-ride the overall water quality score. For example, if a pH value of 1 is recorded then the indicator score for pH will be zero and the overall water quality score should also become zero. Potential critical indicators are pH, diel DO, diel temperature and conductivity.
- As more data is collected, the best way to integrate the indicator scores to derive the overall theme score can be determined.
- As more data is collected, a sensitivity analysis should be undertaken to determine whether there is redundancy in the indicators used.
- As further research is conducted on the biology of south-west macroinvertebrates, fish and crayfish, this should be incorporated into the theme and used to help interpret the indicator and overall theme score. In general, the biology of these faunal groups is poorly understood.

3.4 Macroinvertebrates

Macroinvertebrates are commonly used as indicators to assess river health as they are widely distributed, relatively immobile, easily identified and easily sampled (Rosenberg & Resh 1993). In particular, macroinvertebrates are targeted for assessment as they are sensitive to environmental disturbance, with even small changes to the physical or chemical environment altering community composition and structure through the loss, addition or replacement of taxa. Macroinvertebrate community dynamics have been shown to reflect a number of anthropogenic activities including: changes in water chemistry (Metzeling 1993), sedimentation (Doeg & Milledge 1991), land use (Kay et al. 2001), flow regime (Wood & Petts 1994), salinity (Kay et al. 2001), heavy metal contamination (Grumiaux et al. 1998) and riparian vegetation loss (Quinn et al. 1992).

A number of indicators can be derived from aquatic macroinvertebrate data. For the RHAS, three indicators were chosen on the basis of what has been found to be effective in other river health programs in Australia. These indicators are AUSRIVAS, SIGNAL 2 and family richness.

AUSRIVAS

AUSRIVAS is a national bioassessment program that uses macroinvertebrates to assess the ecological condition of Australian rivers and streams. AUSRIVAS uses the concept of ‘departure from natural condition’ to monitor river health, where the presence or absence of macroinvertebrates can provide an overview of the prevailing conditions and health of a waterway (Halse et al. 2002). The model compares the macroinvertebrate families observed (O) at a site to those expected (E) to occur under a minimal impact scenario to calculate the Observed over Expected (O/E) ratio. The value of the O/E ratio can range from zero (none of the expected families found) to one (all of the expected families found) (Halse et al. 2002). It is possible to get a score greater than 1 where more families were found than expected. The O/E scores are assigned to categories or bands that describe different levels of biological condition, ranging from 'richer than reference' condition (containing more families than expected) to 'impoverished' (containing very few of the expected families) (Halse et al. 2001). These bands were assigned scores in the RHAS.

The AUSRIVAS model was found to lack sensitivity in distinguishing between the sites sampled. From a limited dataset (n = 20), the AUSRIVAS model categorised approximately half the sites as ‘significantly impaired’ and the rest as ‘severely impaired’. The actual sites themselves appeared to exhibit a much broader range of condition as they varied from a site in a forested drinking water catchment to sites in urban drains. To increase its sensitivity, it may be necessary to develop a model specifically for the Swan Canning catchment, or develop models that are based on a lower level of taxonomic resolution. Developing a model specific to the Swan Canning catchment may be problematic given the lack of suitable reference sites for the system.

SIGNAL

The SIGNAL 2 (Stream Invertebrate Grade Number – Average Level) score was developed by Chessman (1995 & 2003) for the assessment of river health. SIGNAL assigns sensitivity grades to families of aquatic macroinvertebrates based on their tolerance to water pollution, particularly salinity and organic pollution (Chessman 1995). Pollution sensitivity grades range from 1 (most tolerant) to 10 (most sensitive). It is an attractive tool as it uses family level taxonomy, (requiring only a moderate level of taxonomic skills) and is an easy indicator to assess and score. From the limited dataset collected, the SIGNAL index was slightly more successful in separating rivers with varying levels of disturbance compared to the AUSRIVAS model. That is, it provided a broader range of scores than the AUSRIVAS model and showed more differentiation between sites.

There are several limitations to using the SIGNAL 2 index for assessing the health of streams in the Swan Canning catchment. The SIGNAL index was initially developed for the Hawkesbury Nepean River system near Sydney and was subsequently revised to include a greater number of taxa and to improve its applicability to other states in Australia (Chessman 2003). The index has so far been validated for assessing stream salinisation and organic pollution discharged from sewage treatment plants (Chessman 1995). Its usefulness in assessing other types of pollution is currently unknown.

Family richness

Family richness is commonly used as a rapid measure of stream health due to its ease of calculation and interpretation. The indicator is based on the principle that healthier streams will have a greater number of macroinvertebrate families than unhealthy streams. Results collected from the Southeast Queensland's baseline monitoring for their EHMP showed that family richness was responding primarily to land use, with secondary responses to channel condition and in-stream habitat (Smith & Storey 2001). From the limited data collected as part of the RHAS, this indicator was effective in distinguishing between significantly degraded rivers and drains and moderately impacted rivers.

Sampling methods for the macroinvertebrate indicators in the RHAS were those developed for AUSRIVAS under the National River Health Program, which is an Australia-wide program (Halse et al. 2002). To save time in the field, the entire sweep was preserved and then sorted in the laboratory using a box sub-sampler and a stereo dissecting microscope. Smith et al. (1999) found that laboratory sorting and picking recovered more families compared to live picks including collecting more taxa from cryptic families. The main disadvantage to laboratory picking is that it takes a longer time to process the samples and it is it also more costly (Smith et al. 1999). Where large quantities of organic matter are present it can be difficult to preserve samples, increasing the risk of sample degradation prior to sorting and identification – which occurred with some of the 2007 samples. Future RHAS assessments will sort the macroinvertebrate samples in the field using a box-sub-sampler and the methodology described in Halse et al. (2002). Using this approach has been found to produce more sensitive results than traditional live picks (Halse et al. 2001).

Recommendations

- Based on current understanding, the macroinvertebrate theme should be assessed annually under baseflow conditions in spring.
- Further investigation to be carried out on the temporal and spatial variability in the macroinvertebrate theme and, from this:
  - the minimum number of sites required in a sub-catchment to enable a robust sub-catchment score to be calculated
  - the required sampling frequency for the theme to be determined.

- The construction of an AUSRIVAS model which uses a lower level of taxonomic resolution, perhaps targeting sensitive groups such as Odonata, Plecoptera and Trichoptera.
- As more data is collected, the best way to integrate the indicator scores to derive the overall theme score can be determined.
- As more data is collected, a sensitivity analysis should be undertaken to determine whether there is redundancy in the indicators used.
- As further research is conducted on the biology of south-west macroinvertebrates, fish and crayfish, this should be incorporated into the theme and used to help interpret the indicator and overall theme score. In general, the biology of these faunal groups is poorly understood.
- Sort macroinvertebrate samples in the field using a box sub-sampler as described in Halse et al. (2002).
- Explore other methods of analysing the macroinvertebrate data, including incorporating functional feeding groups and community composition.
- Investigate the possibility of using indicator species.

3.5 Fish and crayfish

Fish and crayfish are used as indicators of river health worldwide due to their position as top-order species (Pont et al. 2007, Smith & Storey 2001 and Harris & Silveira 1999). Attributes of fish and crayfish that make them suitable indicators of river health include:

- Their relatively long life spans (most species) – used to reflect both long-term and current water quality conditions.
- They are highly mobile and so are less affected by differences in microhabitat compared to smaller organisms.
- Their tolerance is generally species-dependent and ranges from very sensitive to highly tolerant. As such, species presence/absence has the potential to predict specific environmental conditions. However, little is known of the specific requirements and tolerance limits of most of the species found in the Swan Canning (and, indeed, the wider south-west of Western Australia).
- They are relatively easy to collect and identify in the field.
- Fish are highly visible and valuable components of the aquatic ecosystems to members of the community; this aids in both project support and understanding of results by members of the public.

Most river health assessment schemes in Australia (Smith & Storey 2001 and Harris & Silveira 1999) use fish data only; however, due to the naturally low diversity of fish species in south-west Western Australia, fish and crayfish data were combined to

increase the pool of potential species and hence the sensitivity of the index. This was supported in a technical workshop held in May 2006.

Two separate sampling methods were trialled within the RHAS for collecting fish and crayfish, these were:

- multi-pass back-pack electrofishing (trialled in 2006 and 2007)
- baited traps (trialled in 2007 only).

Electrofishing was carried out using a standard effort backpack multi-pass method, incorporating sampling over a 40 m stretch to provide data on both the abundance and size class of fish and crayfish. This method was chosen as it has been used in other fish population studies within the Swan Canning catchments (Storey 1998 and WRM 2000) and is popular in other parts of Australia (Smith & Storey 2001 and Harris & Silveira 1999).

Trapping was undertaken over approximately a 100 m stretch (depending on habitat availability) with traps set overnight (24-hour period) to allow time to attract fish and crayfish into the trap and for any diurnal changes in species composition to be reflected in catch data (i.e. nocturnal species).

Only data gathered from trapping methods were analysed within the RHAS as, compared to electrofishing, trapping resulted in:

- a greater number of individuals per site
- a greater overall diversity (both exotic and native) of fish and crayfish collected
- the collection of more cryptic/rare species, especially nocturnal varieties.

The use of trapping techniques for fish/crayfish provides a broader application for assessing river health in that, unlike back-pack electrofishing, it is not limited by depth of the system and does not require expensive equipment to undertake. Due to this, some sites within the RHAS were either not able to be sampled by electrofishing methods or the sample location was moved. Deeper pools are potential habitats for fish and crayfish (Hutchinson 1992 and Storey 1998) and should be incorporated into collection methodology.

Note: in terms of methodology, electrofishing does provide greater confidence in obtaining quantitative data, as it samples animals within a defined trapping zone and is less-affected by catchability, i.e. foraging behaviour. Further, the presence of predators can influence trapping results, as they can enter traps to take advantage of prey species or their presence in traps may prevent prey species from entering.

Determining system health based on fish/crayfish assemblages ideally compares collected taxa with the diversity and abundance patterns that existed pre-European settlement. As pre-European condition is unknown, it was not possible to perform this type of assessment for the RHAS. A reference condition approach is also commonly used to compare test sites to minimally impacted reference sites to determine expected species versus observed.

The fish-crayfish index developed for the RHAS has been determined based on two elements. The first is an assumption based on professional opinion regarding the species expected at the sampling sites. The second relies on assessing each system in terms of overall ecological stability. The scoring system is still preliminary and is based on limited sites and samples. It will require further refinement as more data become available.

Recommendations

- Based on current understanding, the fish and crayfish theme should be assessed annually under baseflow conditions in spring.
- More research should be conducted to determine the appropriate sampling effort per site to adequately represent the fish and crayfish present.
- Further investigation to be carried out on the temporal and spatial variability in the fish and crayfish theme and, from this:
    - the minimum number of sites required in a sub-catchment to enable a robust sub-catchment score to be calculated
    - the required sampling frequency for the theme to be determined.
- As more data is collected, the best way to integrate the indicator scores to derive the overall theme score can be determined.
- As more data is collected, a sensitivity analysis should be undertaken to determine whether there is redundancy in the indicators used.
- As further research is conducted on the biology of south-west macroinvertebrates, fish and crayfish, this should be incorporated into the theme and used to help interpret the indicator and overall theme score. In general, the biology of these faunal groups is poorly understood.

4 Discussion

The River Health Assessment Scheme (RHAS) was developed to assess the health of waterways in the Swan Canning catchment. The program was based on selecting and developing a suite of indicators that would reflect the organisation (biodiversity, species composition, food web structure), vigour (rates of production, nutrient cycling) and resilience (ability to recover from disturbance) of local aquatic ecosystems (Rapport et al. 1998 and Bunn & Davies 2000).

Indicators for the RHAS were selected so that they reflected the organisation (biodiversity, species composition and food web structure), vigour (rates of production and nutrient concentrations) and resilience (ability to recover from disturbance) of local aquatic ecosystems. Due to a lack of suitable reference sites and limited historical data (with the exception of water quality data), the effectiveness of selected indicators was predominantly assessed using existing guidelines, models of ecological health assessment developed for other geographical areas and expert opinion.

Based on data gathered in the RHAS, the indicators selected were shown to be effective in determining the ecological health of waterways in the Swan Canning catchment. Of the five themes, fish and crayfish and macroinvertebrates appeared to be the most sensitive in distinguishing between the health of sites. Water quality was the least useful of the themes at distinguishing between sites. The assessment of water quality alone has limited application, although it can aid in the interpretation of biological data and identifying some disturbances. For example, changes in water chemistry can result in physiological responses in biota such as increased respiration and reduced growth (Rosenberg & Resh 1993), which could be used to explain aberrations in fish/crayfish dynamics. Physical form and riparian vegetation distinguished well between minimally impacted and highly impacted sites, but clarity was lost in sites falling between these extremes.

Overall, the fish and crayfish theme appeared to show the clearest gradient of scores between the most and least impacted sites. The other biological theme, macroinvertebrates, did not perform as well. However, the value of macroinvertebrates as indicators of river health has been demonstrated in a number of programs worldwide (Hawkins et al. 2000, Clarke et al. 2003 and Bady et al. 2005) so their continued inclusion in the RHAS is justified. Future projects should examine alternative scoring methodologies for the macroinvertebrate theme, including examining community composition and functional feeding groups. More power in the existing indicators may also be obtained if macroinvertebrates are identified to a lower taxonomic level. The viability of constructing an AUSRIVAS model which uses a lower level of taxonomic resolution than family, especially for sensitive groups (such as the Odonata, Trichoptera and Plecoptera) should also be investigated.

The current method employed for integrating the individual indicators to formulate an overall theme score is simplistic. In the current scoring methodology, individual indicators are equally weighted; that is, each indicator contributes a similar proportion of the overall score. The addition of many indicators together can cause low scoring

indicators to be overshadowed in the overall theme score. This was clearly demonstrated in the water quality theme and to some extent in the vegetation and physical form themes. The sensitivity of the water quality theme was reduced due to the combination of multiple indicators – which scored well, over-shadowing one or two indicators, which scored poorly. In future, weighting indicators may need to be considered to reduce this over-shadowing effect. In some cases it may be worth using the precautionary approach and assigning the lowest scoring indicator as the overall theme score, this should especially be investigated for the water quality theme.

The RHAS was developed from a limited dataset collected from a small number of sites (n = 20) in the spring of 2007. These data were used to develop the scoring protocols for all the indicators used in the RHAS. One of the constraints of using such a limited data set is that where there is a lot of variation, both spatially and temporally, it has not been accounted for. Hence, the collection of additional data are required to properly validate the scoring methodologies outlined in the current RHAS. It is recommended that validation of the current guidelines will require a minimum of five years of data.

It is also recommended that future assessments using the RHAS should adopt the following time frames:

- Water quality theme to be monitored on a monthly basis. Water quality can be highly variable and hence collection on a monthly basis will help account for seasonal variability.
- Riparian vegetation and physical form to be monitored every five years (unless a catastrophic event occurs; for example, a fire or flood).
- Biological data (macroinvertebrates and fish/crayfish) to be monitored annually in spring under baseflow conditions.

Interpretation of indicators was often complicated by a lack of underpinning knowledge in regards to the biology of south-west macroinvertebrates, fish and crayfish. This was a consistent issue across all themes. Knowledge of the biology of south-west biota is critical in further validating the RHAS.

Further information requirements on the biology of fish and crayfish includes:

- general and reproductive biology
- understanding species migration and the effect of in-stream barriers on fish passage
- niche occupation
- species tolerance ranges to in-stream conditions.

Further information requirements on the biology of macroinvertebrates includes:

- species tolerance ranges to in-stream conditions.

The RHAS provides a good foundation with which to assess the health of rivers in the Swan Canning catchment in a manner that captures the broad themes of ecological integrity: vigour, organisation and resilience. Although the data collected in the major field trial were limited both spatially and temporally, indicators used appeared to adequately assess the health of streams and drains.

Note: the RHAS has been developed for waterways in the Swan Canning system only and should not be applied outside this area. If river health assessment schemes are to be developed in other areas, then a similar process of indicator selection and trialling will need to occur. The RHAS may be used as a starting point when developing any future river health monitoring tools in Western Australia.

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