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Assessing river health and environmental flow requirements in Chinese rivers

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Australian AID

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Partners

中国水利

YELLOW RIVER CONSERVANCY COMMISSION

Contents

Acronyms

ACEDP	Australia-China Environment Development Partnership
ANZECC	Australian and New Zealand Environment Conservation Council
AusAID	Australian Agency for International Development
BMWP	Biological Monitoring Working Party
CAS	Chinese Academy of Sciences
CRAES	Chinese Research Academy of Environmental Science
DRNM	Queensland Department of Natural Resources and Mines
EPT	Ephemeroptera Plecoptera Trichoptera
FD	Flow Variation Degree
FECO	Foreign and Economic Cooperation Office, Ministry of Environmental Protection
FSR	Flow Stress Ranking
GIWP	General Institute of Water Resources and Hydropower Planning, MWR
IBD	Biological Diatom Index (Indice Biologique Diatomées)
IBI	Index of Biotic Integrity
IFD	Index of Flow Deviation
IFH	Index of Flow Health
IPS	Specific Pollution Sensitivity Index (Indice de Polluosensibilité)
IWC	International WaterCentre
MEP	Chinese Ministry of Environmental Protection
MWR	Chinese Ministry of Water Resources
PCO	Program Coordination Office
PRWRC	Pearl River Water Resources Commission
QA/QC	Quality Assurance/Quality Control
SEWPAC	Australian Department of Sustainability, Environment, Water, Population, and Communities
TN	Total Nitrogen
WWF	World Wide Fund for Nature
YRCC	Yellow River Conservancy Commission

Project team

This study was undertaken by a large team of Chinese and Australian experts. The team included:

- steering committee that had broad oversight of the project and was responsible for reviewing project outcomes at key milestones
- the 'Australian' project team, led by the International WaterCentre, who worked across all aspects of the project and included experts from a number of Chinese institutions
- the Chinese project teams for each pilot study primarily consisted of staff from the Yellow River Conservancy Commission (YRCC) for the Yellow River pilot; the Chinese Research Academy of Environmental Science (CRAES) for the Liao River pilot; and the Pearl River Water Resources Commission (PRWRC) for the Pearl River pilot
- supervisory and support teams from agencies within the Chinese Ministry of Water Resources (MWR) and the Chinese Ministry of Environmental Protection (MEP) who oversaw and guided the general direction of the project from a central government perspective, and provided logistical support to various activities.

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Executive summary

The River Health and Environmental Flow in China Project (the project) was undertaken with China's Ministry of Water Resources (MWR) and Ministry of Environmental Protection (MEP) from August 2009 until March 2012 with a budget of approximately $3.9 million. The project formed part of the Australia–China Environment Development Partnership (ACEDP).

The project aimed to strengthen China's national approaches for improving river conditions through monitoring river health, assessing environmental flow requirements, and developing policy responses. The project involved four sub-projects. Three sub-projects were pilot studies incorporating field assessments across three different river basins – the Pearl, Yellow and Liao River basins. River health and environmental flow assessments were completed for pilot sites in all three river basins. The fourth sub-project focused on developing a national framework for environmental flows. The results from all four sub-projects were used as the basis for developing national policy recommendations. Significant training activities were also carried out to improve the capacity of Chinese water managers.

This report describes (i) the river health and environmental flow assessment methods and results and (ii) recommendations for implementing these methods in China.

The Chinese context

River health and environmental flow assessment and implementation are high priorities for the Chinese government. The *No.1 Policy Document* issued by the Central Committee of the Communist Party and the State Council in 2011 focuses on developing and managing water resources. In setting a roadmap for the next 10 years of water conservancy projects, the *No.1 Policy Document* recognises the challenge of conserving and protecting water resources and the importance of 'economic, ecological, and national security' as well as flood control, water supply, and food security.

The policy requires water allocation caps to be set, water restoration planning to be completed, and indicator systems for water savings and protection to be established and implemented. A number of major Chinese government projects are already underway within both MWR and MEP to achieve these objectives. These projects include the development of a national river health assessment program for the major river basins, and water allocation planning across the country. The project and the recommendations in this report are designed to inform this work.

Assessing river health

River health monitoring programs can identify threats and the causes of poor health, help prioritise and guide management responses, and assess the effectiveness of those responses. This information is critical when billions of dollars are being spent on reducing pollution and improving river health, as is currently the case in China. Therefore, ongoing efforts to develop national systems for routine river health monitoring, assessment and reporting are strongly supported.

Two different methods were tested for selecting indicators and assessing river health. One method was used in the Pearl and the Liao Rivers, and the second method was used in the Yellow River.

In the Pearl (Gui River catchment) and Liao (Taizi River catchment), field sampling was undertaken to collect data on water quality, benthic macroinvertebrates, fish, algae, aquatic and riparian vegetation, and physical form.

Potential indicators were tested against the levels of human disturbance across the catchment, which was estimated based on land use in the catchment using GIS tools. Indicators that responded in a predictable way to changes in disturbance were selected. This approach was designed to identify indicators most likely to show changes in river health.

Rivers were divided into different classes for the purposes of setting reference values and for reporting. Reference values were established using existing Chinese standards, data collected from sites in the catchment, expert opinion, and values derived from international studies and standards. At each site, a score from 0–1 was assigned for each indicator. Using this benchmark, sites were scored on a scale from 'very good' to 'critical'. Scores were aggregated to produce combined scores for different indicator groups, sites and regions.

In the Yellow River indicators and objectives were set based on existing management targets. These management targets related to:

- **Ecology:** data on fish, macroinvertebrates and riparian plants were assessed against reach-specific reference values to provide a score on ecological condition. In addition, an index for riparian vegetation in the delta was developed, using satellite images to assess the composition of the vegetation in key wetlands and any loss of wetlands to agriculture.

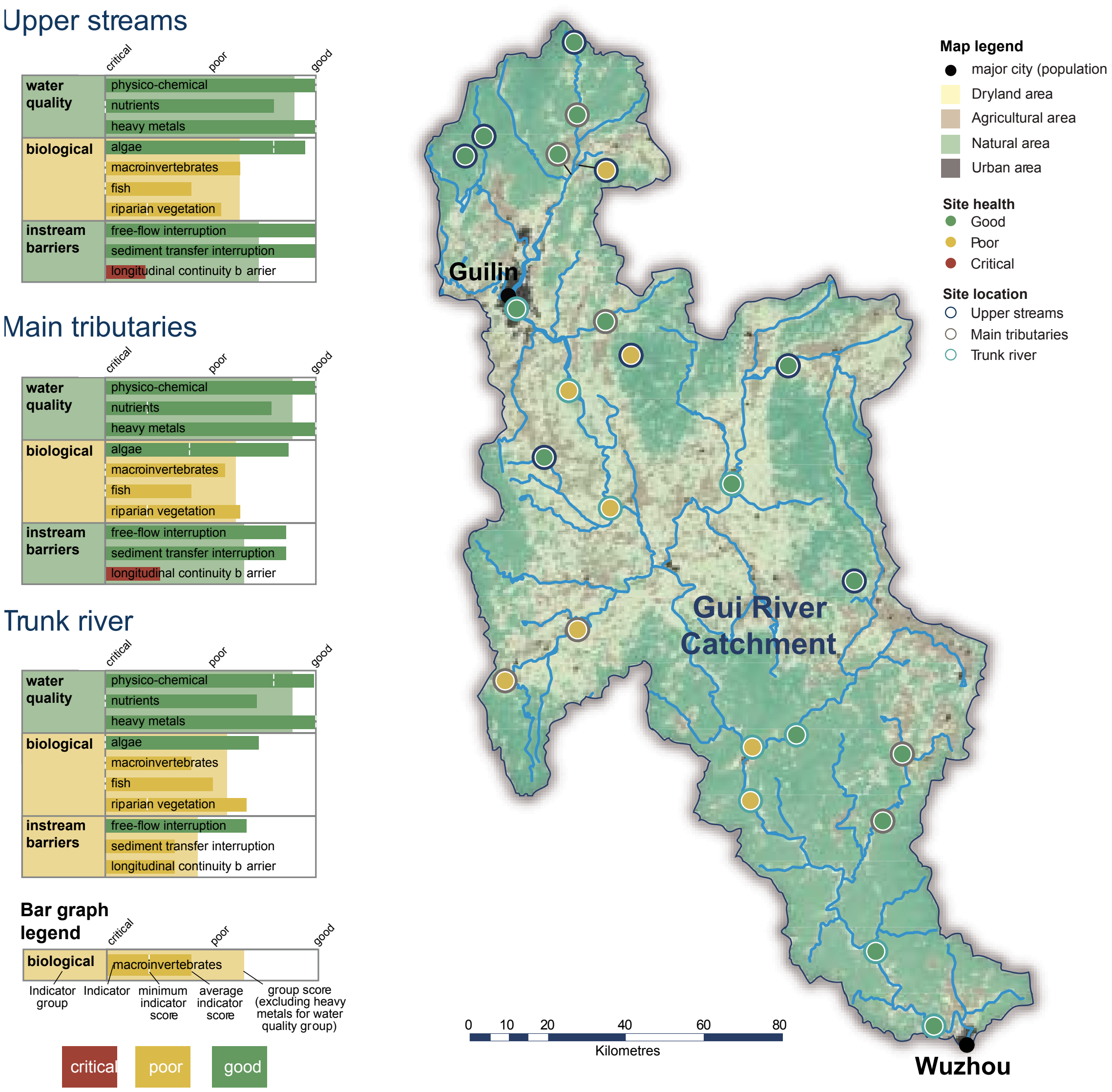
- **Water quality:** based on the degree of achievement of a target grade.
- **Physical form:** based on channel capacity and the movement of sediment.
- **Socio-economic factors:** including indicators related to water supply, hydropower production, navigation, and flood risk.

Hydrology was used as an indicator of river health in all three pilot studies. Two existing rapid-assessment methods were used, as well as two methods developed as part of the project, which are described below.

- The Index of Flow Deviation (IFD) uses eight indicators to represent different aspects of flow regime that are of universal importance for river health. Monthly flow data was tested against a reference flow series to assess the extent of deviation from the natural range. A software tool was developed to automatically calculate a score for any flow time-series.
- The Index of Flow Health (IFH) assesses the extent to which certain environmentally important flows are being achieved. This method requires that an environmental flow assessment first be undertaken.

An assessment was made of the current condition of the rivers in the pilot studies. River health report cards were prepared for the rivers in the pilot studies and a summary river health report card was also prepared. The results for the Gui River are shown in Figure 1. The suitability of specific indicators for future use in China, as well as an assessment of the health of the rivers in the pilot study rivers are summarised in section 2.6.

Figure 1: Map of the Gui River showing the results for each sampling site, and for each of the indicator groups assessed. Similar results and graphics were generated for the other pilot sites.

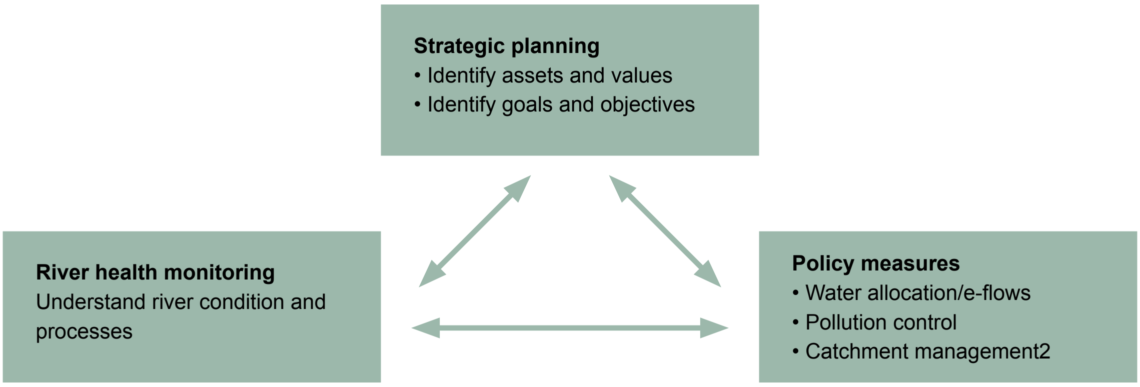


Recommendations for developing a national river health monitoring program

1. Link to planning and policy responses: River health monitoring in China should be clearly linked to:
   a) basin and regional water resources planning: by helping to identify important riverine assets and processes and those under threat, as well as to identify if goals for the catchment are being achieved
   b) policy measures: river health monitoring should help prioritise regions where policy responses are required, identify the type of management action that is most appropriate, and assess the effectiveness of those measures.

Figure 2 shows the relationship between these different elements.

Figure 2: Links between river health monitoring, planning and policy measures.



2. **Draw on existing information to prioritise actions:** Data from existing water quality and hydrological monitoring, as well as remote sensing, can provide significant information on the condition of rivers across a large area, at a relatively low cost. This information should be used to determine areas where more detailed assessments are required, such as areas at greater risk of high ecological or socio-economic importance.

3. **Set clear goals and objectives for river health monitoring:** These goals and objectives should be set at both the national and catchment levels. It is also important to have clear objectives for individual rivers: with a clear vision statement, it is possible to identify the assets and values that will reflect the vision and the water quality and ecosystem health objectives required to protect the assets and values. Setting clear goals and objectives will also allow an appropriate monitoring program to be developed.

4. **Select appropriate indicators for the assessment:** The selection of indicators should be guided by their relevance to important environmental assets and values, and their likely response to different threatening processes. Indicators must respond to stressors in a predictable way. Indicators should reflect the range of ecosystem health values of interest, and be responsive to the range of threats that may occur. The project tested indicators against catchment disturbance. This method would also be appropriate for testing the suitability of indicators in many circumstances.

5. **Focus on a consistent approach to collecting data:** After basic data about a river system has been collected, the suitability of a large number of indicators can be calculated and assessed. Initially, it is important to focus on collecting high quality, raw data – the best indicator can be determined at a later date. The data collection process should be supported by a rigorous quality assurance program, which can be implemented consistently by many people. The quality of any river health analysis and subsequent recommendations depends on the quality of the data. Consistent processes need to be established for sampling, data entry, data storage and use, and laboratory analyses. Reliability in field and analytical data is best achieved by implementing a quality assurance or quality control (QA/QC) plan.

6. **Set appropriate benchmarks and threshold values for the indicators:** Reference values for each indicator should be set that reflect (i) the type of river (ii) the management objectives (iii) the desired vision for the river. While there is some scope to draw on existing Chinese and international standards and values, developing national standards for river health monitoring should be a priority. Developing national standards should be undertaken after a core set of indicators has been selected. Experience elsewhere suggests that this is a long, but critical, process to ensure the validity of the monitoring program. Reference values should be refined over time as more data is collected.

7. **Classify rivers into different types:** Classification allows for comparisons to be made between similar types of rivers, including setting appropriate reference values for different river types. A national river classification system would be valuable in supporting river health assessment programs, as well as other management activities.

8. **Adopt a common reporting framework:** The indicators and reference values adopted across China do not need be the same, provided there is a common reporting framework so the results for different rivers can be compared. A common reporting framework can be achieved by scaling results in the same way, so that a 'good' score or a 'poor' score is equivalent, even if different indicators are used. Such an approach allows for flexibility within a national monitoring program to ensure that indicators and reference values are appropriate to local conditions.

9. **Report on the results:** Report cards provide a valuable tool for communicating large amounts of complex information in a simple way. The way information is presented in a report card must make sense to the audience. It is primarily a communication tool and needs to be underpinned by a more technical report explaining the data.

10. **Implement the monitoring program to inform management:** River health monitoring and reporting need to be developed in the context of an adaptive process that is informed by rigorous science, that guides management actions, and is responsive to changing perceptions and values of stakeholders. There should be a strong collaboration and communication between policy makers and the scientists involved in the program, and programs must be sufficiently planned and resourced.

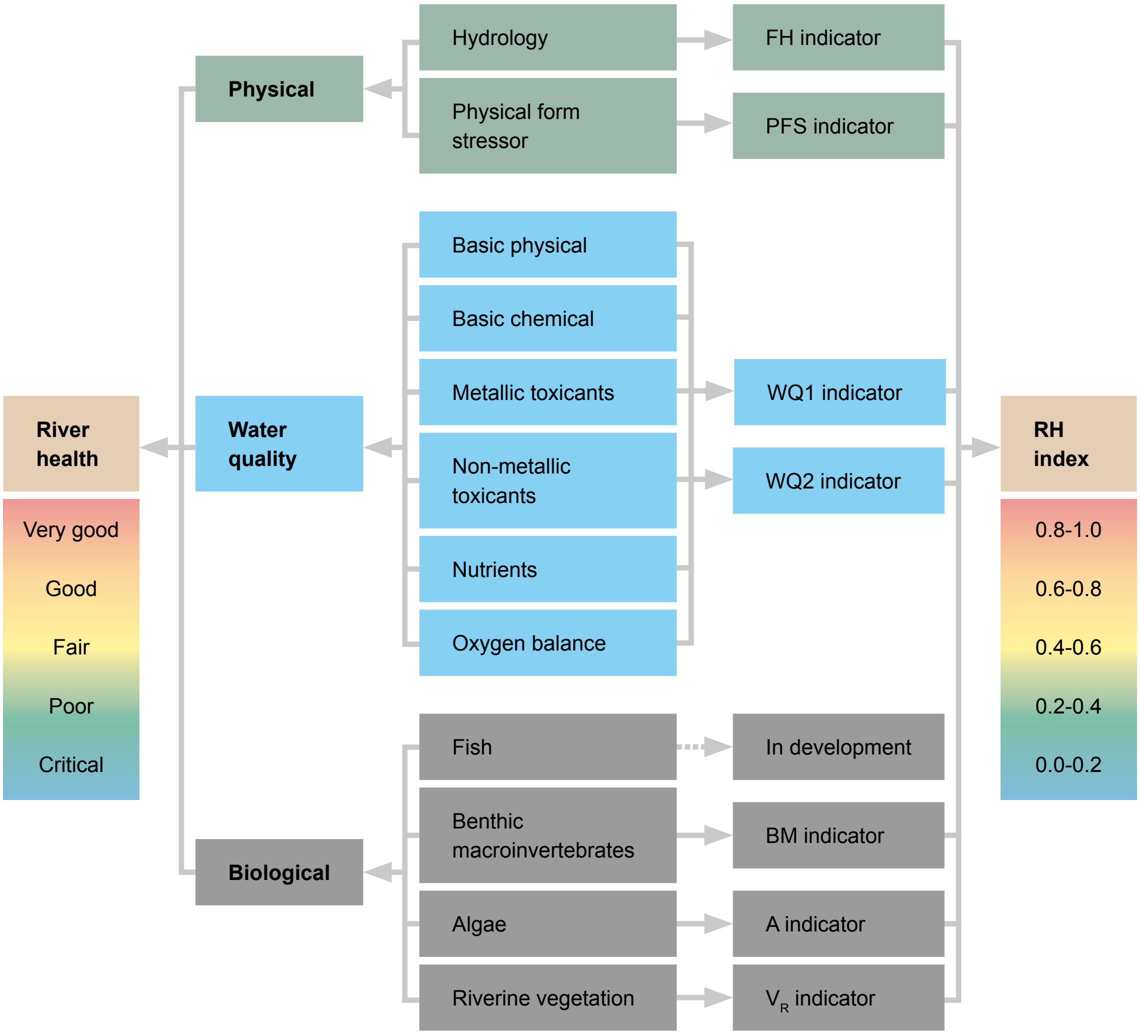
Guideline for assessing river health

The project developed a draft national guideline for assessing river health. The guideline is based on the results from the project and incorporates the recommendations listed above. The guideline also recognises the challenges of data availability and limited resources, together with the need for an approach that can be used in a variety of river systems.

The framework for the draft guideline is shown in Figure 3. The guideline includes principles for selecting indicators, defining reference values, selecting sampling sites, determining frequency and timing of sampling, and data measurement, storage, and reporting.

The guideline should be updated over time as more data becomes available, allowing for reference values to be refined and new indicators to be used.

Figure 3: Proposed framework for assessing river health.



Assessing environmental flow requirements

Environmental flows are critical for maintaining river health and protecting the benefits derived from riverine goods and services. The significance of elements of the flow regime for river assets and processes should be determined when developing water allocation plans.

Many of the methods for assessing environmental flows adopted in China, to date, have been simplistic, hydrology-based methods. The project developed an alternative generic method for assessing flow needs. This assessment method is based on other asset-based, holistic environmental flow assessment methods used in countries such as Australia, South Africa, and the United States.

The assessment method can be adapted to the river type; for the important assets in the river; and for the available time, data and resources. The project applied the assessment method to the lower Yellow River, the Li River (part of the Gui River), and in the Taizi River. However, the assessments varied in detail; a desktop assessment was undertaken for the Taizi River, while a comprehensive assessment was undertaken for the Yellow and Li Rivers. The following describes steps taken in the comprehensive assessment of the Yellow River:

Step 1: *Define reaches and identify key river assets and processes*. The lower Yellow River was divided into four reaches, based on physical and ecological characteristics. Various wetlands, together with the delta and the river channel, were identified as key assets to be protected.

Step 2: *Set management objectives for each asset or process*. A workshop involving Australian and Chinese experts established flow objectives – including timing, frequency, and duration of flows – for each asset or process, and within each river reach. Flows relating to geomorphologic, vegetation, macroinvertebrate, fish, waterbird, and water quality objectives were set.

Step 3: *Develop hydraulic models of representative sections.* River surveys were conducted and 1-D and 2-D models used to determine the flows required to achieve the hydraulic objectives, such as watering important wetlands and providing fish habitat.

Step 4: *Develop preferred environmental flow rules*. Flow rules were set based on achieving the management objectives. Two environmental flow options were developed: one has a low risk for achieving good river health and the other has a medium risk.

Step 5: *Assess different water allocation scenarios*. Economic and hydrological models were developed to assess the demand for water in the basin, and to assess how water resource scheduling could be implemented to balance demands with preferred environmental flow rules.

For each reach of the Yellow River, recommended flows were specified, including details on the required flow magnitude, mean annual frequency and duration, inter-annual frequency, maximum rates of rise and fall, and time of the year. Figure 4 shows the recommended flow regime for reach 1.

The flow options were constrained by operational requirements, including the need to keep flow within the confines of the main channel due to the risk to human life and socio-economic values. The current environmental flow practice in the Yellow River is similar to the low-risk environmental flow regime recommended by the project. As a result, compliance with the flow regime has been fairly high in recent years.

The project has been designed to provide scientific support for the benefits of environmental flows, so management decisions can be made with greater confidence.

Figure 4: Low-risk environmental flow regime for reach 1 of the lower Yellow River.

Objectives met	Flow component	Hydrologic criteria	Mean annual frequency/ duration	Inter-annual frequency	Timing
F1; M1	Cease to flow	No cease to flow	Continuous	100% of the time	All year
B1; B2; B3, F2; WQ1, WQ2, WQ3, WQ4; V3; M2; M5; F3; F4; F11; F16	Low flow	Dec ≥ 307 Jan ≥ 280 Feb ≥ 321 Mar ≥ 377 Apr ≥ 463 May ≥ 430	Continuous	≥ 75% of the time	Dec - May
F6; F7; F9; V1; B5; M3; M4; F14	High flow	Jun ≥ 434 Jul ≥ 783 Aug ≥ 1,137 Sep ≥ 1,124 Oct ≥ 866 Nov ≥ 543	Continuous	≥ 75% of the time	Jun - Nov
V3; V4; F10	Low flow pulse	≥ 2000	≥ 1 per year / 1 – 30 days; rates of rise and fall within natural range	≥4 in 5 years	Nov - May
G1, G2, G3, G4, WQ6; B6; B7; B8; F12; F13; F5; F10	Bankfull	3000 – 4000	≥ 1 per year / ~10 – 30 days duration; rates of rise and fall within natural range	≥4 in 5 years	Jun – Sep

A similar process was followed for the Li River. This led to a recommended flow regime that consists of three flow components:

1. **Low flows:** to enhance dry season base flows, to improve navigation, and to prevent periods of poor water quality.
2. **High flows:** to protect existing wet season base flows and to maintain habitat necessary for fish reproduction.
3. **Flow pulses:** to maintain dry and wet season flow pulses, to maintain riparian vegetation, to maintain habitat, and to support fish reproduction.

Recommendations for implementing environmental flows

A draft national environmental flows framework is proposed (Figure 5). The framework identifies the elements of a national system for determining environmental flow requirements and for incorporating these elements within allocation and management arrangements. The framework addresses requirements related to the policy and enabling environment, assessment and water allocation planning, and implementation of environmental flows. Fundamentally, the framework provides for:

- determining the flows that need to be protected or provided to maintain the riverine environment in a desired condition
- identifying management and regulatory systems to ensure that those flows are provided and protected.

The framework should be implemented in accordance with the following recommendations.

1. **Identify and define environmental goals and priorities:** Environmental flow assessment and implementation needs to be undertaken with a clear understanding of the broad environmental objectives for the basin: what ecological assets and services are of importance and in what condition will they be maintained? Environmental flow objectives should be determined based on the requirements to protect these assets and services.

2. **Tailor the approach to suit the situation:** Flow requirements to maintain ecological health can vary significantly between different river types, and can be based on the particular assets and services of importance. The types and size of flow that are suitable to one river system will not necessarily be applicable in another. The management approach may need to vary depending on whether a system is regulated or unregulated, the main threats, and the types of flows to be protected or provided.

3. **Recognise the limitations of basic hydrological assessment methods:** Hydrology-based methods, such as the Tenant method, are widely used because of their simplicity. However, these types of methods are unlikely to provide a scientific basis for assessing environmental flow needs in most Chinese rivers. Assessment methods need to be applied that can account for the different hydrology, hydraulics, and ecology in Chinese rivers.

4. **Cap abstractions as soon as possible:** It is much easier to implement requirements on new users than to enact changes to existing use. Experience demonstrates that it is better to adopt a precautionary approach and to introduce a cap on abstractions now – even where environmental water requirements may be unclear – and limit the risk of a difficult future water re-allocation process. At the same time, where water is already over-allocated, a cap must be seen as only the starting point, with subsequent efforts made to reduce water usage.

5. **Recognise the links between environmental protection, water allocation, and development objectives:** Environmental water needs should provide the foundation for water allocation planning. This does not mean that environmental flow requirements must always take priority, but they should always be a central consideration in the allocation process. The water allocation planning process should provide the mechanism for identifying and reconciling competing demands on the basin's resources, and more broadly be done in a way that recognises the role of water in development and aligns with overarching developmental and environmental objectives.

6. **Adopt an approach that protects environmental interests during periods of scarcity:** Past practice suggests that environmental flow regimes are particularly susceptible to curtailment during periods of water shortage. Water sharing arrangements should ensure an equitable and appropriate approach to sharing water during these times.

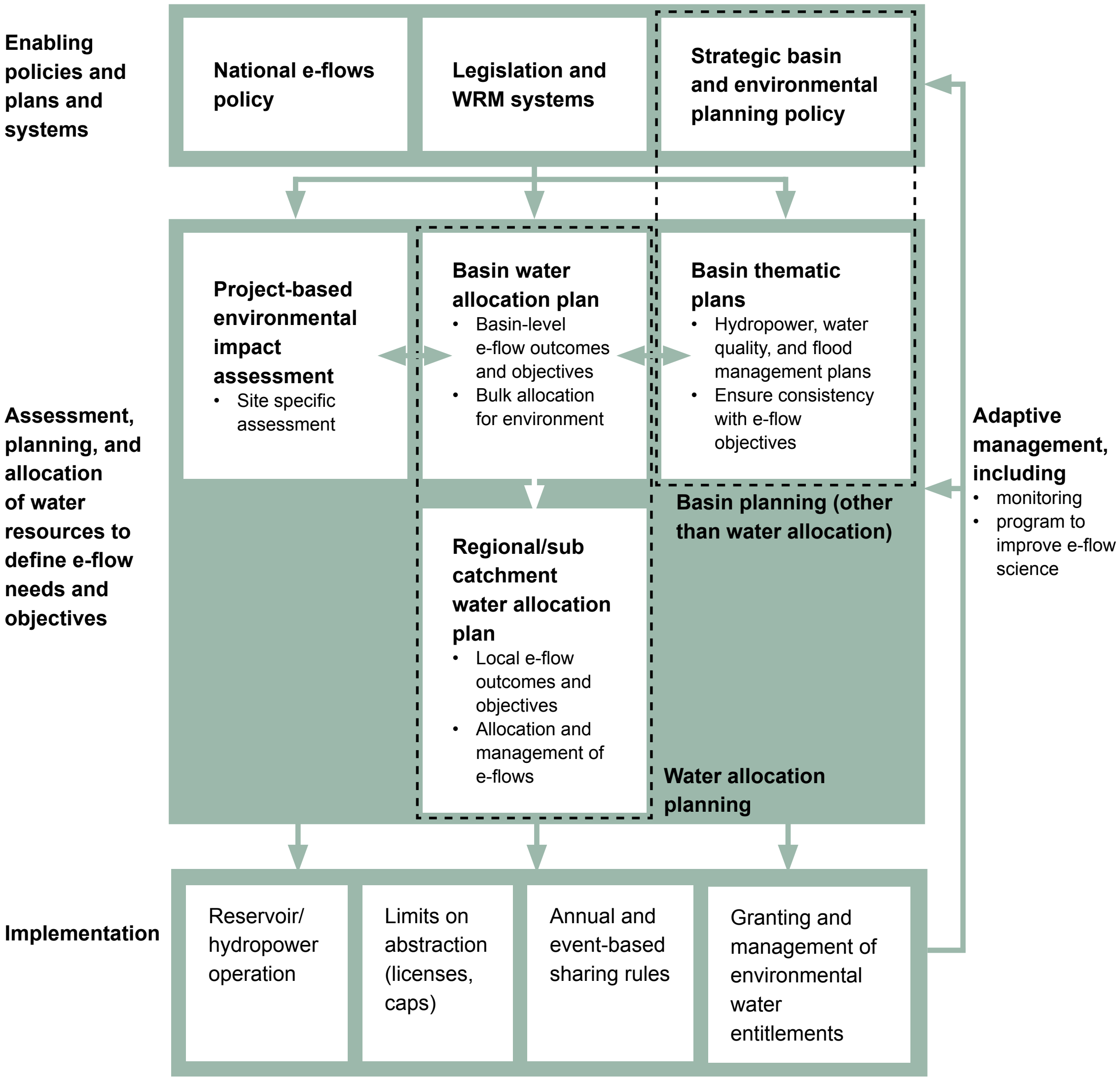
7. **Maintain capacity to adjust to changing circumstances:** Changes in climate, the economic and social situation, government priorities, and scientific understanding of a river basin can all require adjustments to the water allocation and environmental flow regime. Management systems should retain sufficient flexibility to be able to adjust to new circumstances.

8. **Make informed decisions about environmental flows and water allocations:** The establishment of environmental flows should be based, to the greatest extent possible, on deliberate, informed decisions. The process of allocating and managing water resources should involve:

   a) Identifying the river's assets, values and functions that are to be protected or restored.
   b) Reserving water to meet the flow needs of those assets, values and functions. This should include provision of a complete flow regime – not just minimum flows – and be based on an understanding of the links between flow and ecology.

   Importantly, where a decision is made to not provide water for the environment (or at least for particular environmental assets) this decision should be made deliberately, rather than by default, and in a transparent way. Such decisions should be made with an understanding of their potential impacts on the river's ecosystems and the goods and services the river would otherwise provide.

Figure 5: National environmental flows framework.



Chapter 1. Project overview

1.1 Background and objectives

The River Health and Environmental Flow in China Project ('the project') is one of a series of projects undertaken as part of the Australia–China Environment Development Partnership (ACEDP). The ACEDP is a five-year program undertaken jointly by the Australian and Chinese governments and funded by AusAID. The broad goal of the ACEDP is to support policy development in China in environmental protection and natural resource management, with a focus on water resources and river basin management.

The project ran from August 2009 until March 2012 with a total budget of approximately AUD3.9 million. The long-term goal of the project was strengthening national approaches for improving river conditions through monitoring river health, assessing environmental flow requirements, and policy responses. The project's scope of services identified six objectives, including:

- river health: to document and trial international approaches to river health monitoring, with consideration given to wider application in China
- environmental flows: to document and trial international approaches to environmental flow determination, with consideration given to wider application in China
- national framework for environmental flows: to develop a national framework.

The other three project objectives relate to capacity building, communications, and monitoring and evaluation. Work on these objectives is the subject of a separate project report.[1]

The project involved four sub-projects. Three sub-projects were pilot studies incorporating field assessments across three different river basins – the Pearl, Yellow and Liao River basins. The fourth sub-project focused on developing a national framework for environmental flows. The results from all four sub-projects were used as the basis for developing national policy recommendations.

The primary Chinese partners in the project were the Ministry of Water Resources (MWR) and the Ministry of Environmental Protection (MEP). The sub-projects were undertaken with various government agencies and institutions under these ministries, as shown in Table 1. A detailed list of those involved in the project is included in at the start of this report.

Table 1: Partners and focus of the four sub-projects.

Sub-project	Partner agency	Project focus
Yellow River Pilot	Yellow River Conservancy Commission (YRCC)	River health and environmental flows assessment
Pearl River Pilot	Pearl River Water Resources Commission (PRWRC)	River health and environmental flows assessment
Liao River Pilot	Chinese Research Academy of Environmental Science	River health assessment
National environmental flows framework	General Institute of Water Resources and Hydropower Planning and Design	National environmental flows policy

River health and e nvironmental flow assessment and implementation are high priorities for the Chinese government. The *No.1 Policy Document* issued by the Central Committee of the Communist Party and the State Council in 2011 focuses on developing and managing water resources. In setting a roadmap for the next 10 years of water conservancy projects, the document recognises the challenge of conserving and protecting water resources and recognises the importance of 'economic, ecological, and national security', as well as flood control, water supply, and food security.

1 International WaterCentre 2012. *River Health and Environmental Flow in China Project: Communications and Capacity Building Report*. International WaterCentre, Brisbane. March 2012.
2 A desktop environmental flows assessment was also completed for the Liao River.

The policy requires water allocation caps to be set, which means environmental flows have to be determined; water restoration planning be completed; and indicator systems for water savings and protection to be established and implemented. A number of major Chinese government projects are already underway within both MWR and MEP to achieve these objectives. These projects include:

- The National Water Pollution Control and Treatment Program, under MEP. This is a 15-year, multi-billion dollar project aimed at improving the health of Chinese rivers, and includes a major component on river health assessment.
- An MWR program to develop a national river health assessment system. A five-year pilot program commenced in 2011 that is trialling draft river health assessment guidelines in a number of key basins nationally. The trial involves assessing river health using water quality, physical form, biological, hydrological and socio-economic indicators.
- The revision of the master basin plans for China's major river basins. This is a major, ongoing program within MWR, which will lead to revised basin master plans and water allocation plans across China. The revised plans will incorporate environmental flow requirements.

1.2 Project methodology and reports

The project involved three main stages:

- **An inception phase.** Technical reports on river health and environmental flow assessment based on international experiences were written and assessment frameworks suitable for China were developed. Work plans were agreed and a number of training activities were completed for staff involved in the pilot work.
- **The pilot studies.** Background reports on the pilot sites were prepared by the relevant Chinese agencies, collating information on the physical and ecological characteristics of the pilot catchments, threats to river health, and management arrangements and priorities. Fieldwork was undertaken to gather further information. Finally, assessments of river conditions and environmental flow requirements were made. Based on the results of this work, the current health and environmental flow requirements of the pilot rivers were assessed, and recommendations about future monitoring programs and other management actions were made.
- **A completion phase.** The findings from across the pilot studies have been distilled and collated into a single set of lessons and recommendations for river health and environmental flow assessment in China. These findings are presented in this report.

The project was extended by approximately 9 months. This extension allowed for (i) draft national guidelines to be developed (ii) operational requirements for implementing a routine river health monitoring system to be identified (iii) environmental flow for the Li River to be assessed (iv) further river health assessments in the Pearl and Liao basins.

The project produced a number of reports. This report draws together many of the key elements of all the project's reports. The project's reports include:

- **Framework and discussion papers.** These papers provide an overview of international approaches to river health and environmental flow assessment and describe a framework and the supporting scientific basis for the project's methodology.
- **Background reports.** These reports describe the physical, ecological and developmental characteristics of the catchments, key environmental assets, threats to river health, and management activities and priorities for each pilot catchment.
- **Pilot study reports.** These reports provide detailed technical information on the river health and environmental flows assessments.
- **River health report cards.** The report cards are brief summaries about the river health assessment work and results.
- **Whole-of-project technical reports.** The technical reports are standalone reports on environmental flows, the use of hydrological indicators of river health, physical form as an indicator of river health, assessing health of large water bodies, operational requirements to support a routine monitoring program, and public participation in river health and environmental flows assessments.
- **Final report and summary of findings.** This (current) report summarises the technical work of the project and the overall conclusions and recommendations.

All these reports are available from the project website at www.watercentre.org.

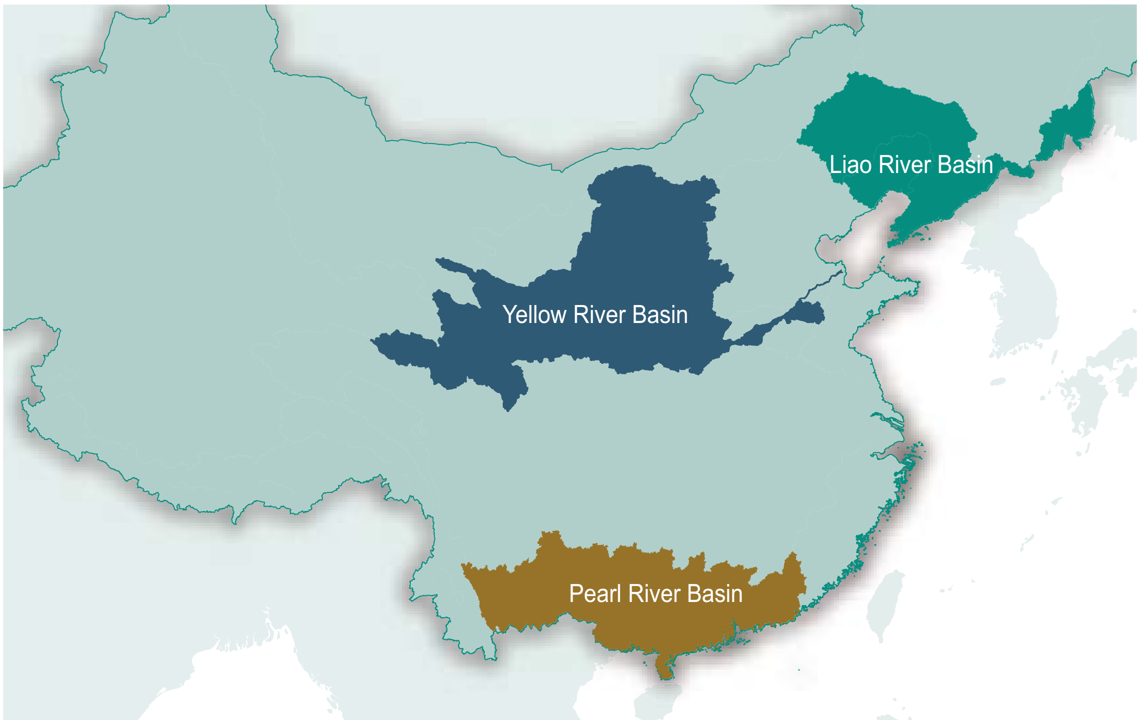
1.3 Introduction to the pilot study areas

The pilot sites were identified by the Chinese team, based on a variety of different criteria, including existing research programs and management priorities and the availability of data. The three pilot sites cover a broad range of different river types, which provided a sound foundation for testing the national applicability of the methodologies trialled in the project.

River health and environmental flow assessments were undertaken in:

- the Taizi River basin, a subcatchment of the Liao River basin
- the Gui River basin, a subcatchment of the Pearl River basin
- the lower Yellow River, defined for present purposes as the area downstream of Xiaolangdi Reservoir, and encompassing around 800 kilometres of river length.

Figure 6: Map showing the location of the three pilot river basins.



Liao River Pilot

Liaoning Province is located in north-eastern China, bordering the Yellow Sea and the Bohai Gulf in the south and North Korea in the south-east. The region was an important mining area and, since the creation of the new China in 1949, has been a major industrial base. These activities resulted in significant impacts on the natural environment over the past 40 years. The Liao River basin has a catchment area of over 232,000 km^2. However, its mean discharge is relatively small, at an average of approximately 500 m^3s^{-1} (Figure 7).

The pilot project work in the Liao River was conducted on the Taizi River, one of the main tributaries of the Liao. The Taizi River has a watershed of 13,900 km2, and a stream length of 413 kilometres. The Taizi River supplies water for domestic, industrial and irrigation purposes for three main cities – Benxi, Liaoyang and Anshan – and has nine tributaries.

The Taizi River catchment is located in China's mid and high latitudes in a temperate, continental monsoon climate zone. The main features of the local climate are a hot rainy season; a sunny, long cold period in winter; and a short spring and autumn. In general, it is wet in the eastern part of the catchment and dry in the western, windy plain, with an annual precipitation ranging from 655–954 mm. There are nine reservoirs in the catchment. Remnant forest accounts for 57.2 per cent of the total catchment area, followed by dry-land farming activities (as opposed to wetland farming such as rice fields), which accounted for 22.3 per cent. The average natural (pre-regulation) runoff at Tangmazai, near the mouth, was 75 m3/s.

The Taizi River has been an important industrial area in the middle of Liaoning Province since the 1950s. Since then, stream health has been severely impacted, including the loss of several fish species. The most significant threats to ecosystem health are from industrial, urban and rural pollution; clearing of natural vegetation within the catchment and riparian zone; construction of in-stream barriers; alteration of natural river flows; and the in-stream extraction of river bed materials.3

Figure 7: Liao River basin, the Taizi River Basin, and sampling sites.

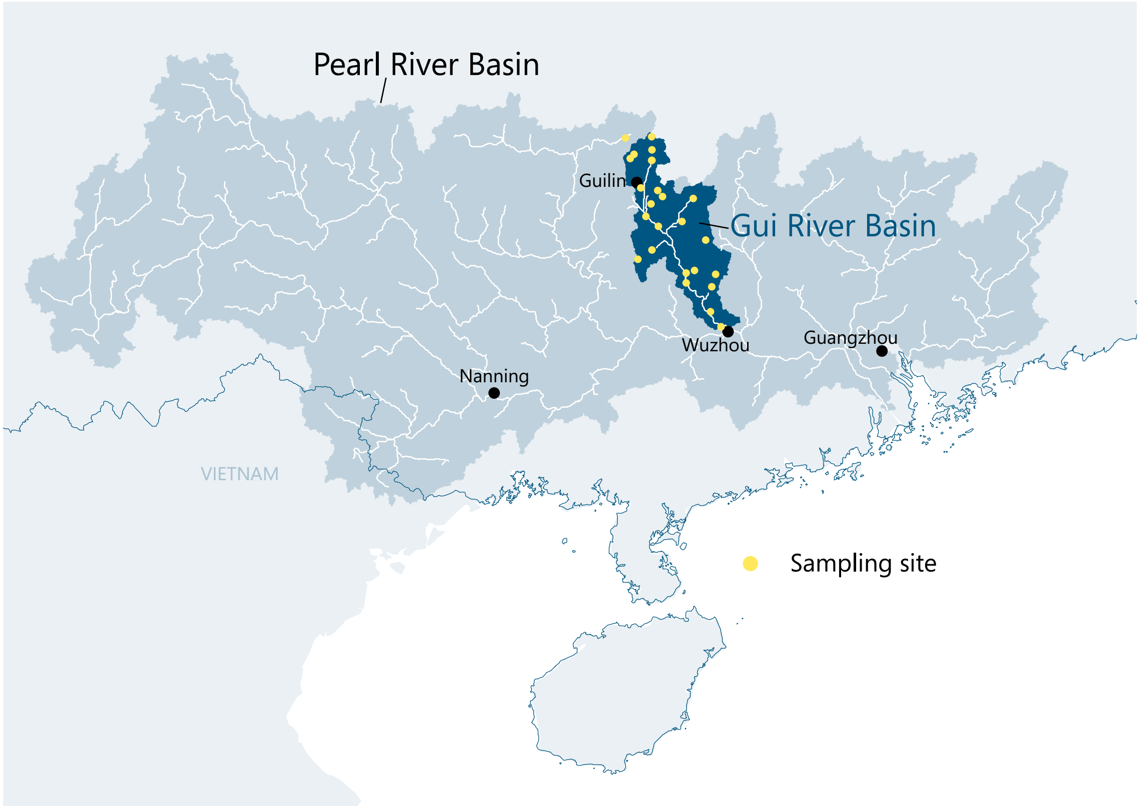
Pearl River Pilot

The Pearl River basin is located in southern China and crosses five provinces, as well as north-east Vietnam. The basin has a total area of approximately 400,000 km^2 and consists of three main tributaries, the Xi Jiang (West River), the Bei Jiang (North River), and the Dong Jiang (East River). The river is about 2,200 kilometres long from the start of the Xi Jiang to the delta, making it China's third longest in length, and is the second largest by volume with an average discharge of 9,500 m^3/s.

The pilot study was conducted on the Gui River, a northern tributary of the Pearl River with a drainage area of approximately 18,790 km^2 (Figure 8). Although relatively small in comparison to other tributaries, the river drains a unique karst landscape and is a famous tourist destination. The climate of the area is subtropical monsoon. Average annual rainfall across the catchment varies from 1,500 to 2,400 mm. More than 75 per cent of the rainfall occurs from March to August and the Gui River has an average annual flow at its mouth of 18.8 x 10^9 m^3 or 597 m^3/s. There are four main reservoirs in the catchment that are used for drinking water supply, flood protection, and maintaining water levels during the dry season for navigation (tourism) purposes.

3 Background information on the Liao and Taizi Rivers is drawn from: CRAES 2010, *Taizi Basin* background report, report to ACEDP project, International Water Centre, Brisbane. Chinese Research Academy of Environmental Sciences, Ministry of Environmental Protection, Beijing.

Figure 8. Map of the Pearl River Basin showing the location of the Gui River catchment.



Environmental assets in the Gui River basin include drinking water source protection areas, nature reserves, water conservation forest reserves, wetland protected areas and river-based tourism. The catchment is still heavily forested. Since the 1970s, there have been significant efforts made to protect water quality in the catchment and to preserve the natural beauty of the river, particularly to support the tourist industry. As such, there are only low levels of industrial development, with many factories in the catchment closed or transferred elsewhere. The main sources of water pollution are non-point source agricultural and urban runoff and sewage discharge, although most of the larger towns now have sewage treatment plants.[4]

Yellow River Pilot

The Yellow River source is located in western China in the Qinghai-Tibetan plateau and flows through seven provinces and two autonomous regions before reaching its mouth at the Bohai. The Yellow River is 5,464 kilometres long with a basin area of 752,443 km^2.

The Yellow River basin is traditionally divided into the upper, middle and lower reaches (Figure 9). Annual mean precipitation in the upper basin is 368 mm, in the middle basin is 530 mm and in the lower basin is 670 mm. The basin is mostly arid and semi-arid land. In the middle reach, the river cuts through the Loess Plateau, which contributes around 90 per cent of the river's sediment load. The sediment load of the lower Yellow River is usually quoted within the range 1.0 to 1.6 × 10^9 tonnes, which would rank it first among the world's rivers for sediment load.

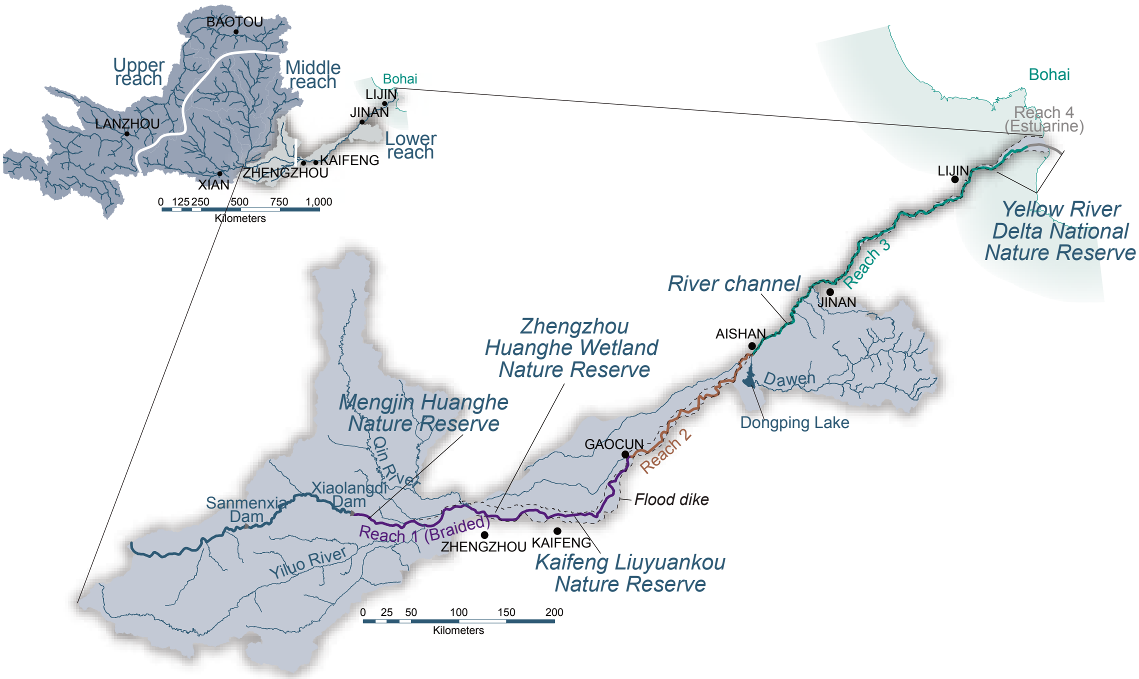
The population within the basin was projected to be 120 million by 2010. The catchment includes 12.6 million ha under agriculture, of which 40 per cent is irrigated with water sourced from the Yellow River. Agriculture is by far the largest user of water, accounting for 80 per cent of the total withdrawal. In the year 2000, 76 per cent of the available water resource was taken for human uses, 10 per cent entered the sea, and 14 per cent was lost to evaporation, interaction between groundwater and deep aquifers, or other unaccounted losses. Therefore, the water resource is relatively scarce, creating a tension between allocating water for the benefit of river health and allocating water for direct social and economic benefit.

4 Background information on the Pearl and Gui Rivers is drawn from PRWRC 2010, *Gui River background report*, report to ACEDP project, International Water Centre, Brisbane. Pearl River Water Resources Commission, Ministry of Water Resources, Guangzhou.

The lower Yellow River has a relatively small local catchment area, with just a few tributaries. Flood dikes constructed along its entire course (except where it abuts valley walls) have severed the natural hydrological connection between the river and the North China Plain. The flood dikes have been in place for many centuries. Vast amounts of sediment are delivered from the Loess Plateau in the middle Yellow River area, and deposition of this material has created a suspended floodplain within the diked section is 3–10 metres higher than the land outside the dikes that for most of the river's course. Sediment reaching the sea has created a vast, morphologically and ecologically dynamic, delta landform.

As part of the first national water resources assessment, the total average annual water resources over the 24 years from 1956 to 1979 was estimated at 73.5 billion m^3, with an estimated average annual runoff of 58 billion m^3 or 1,838 m^3/s at Lijin. This is the figure used in the 1987 Water Allocation Scheme, which is the basis of the current water sharing and allocation arrangements. However, evidence suggests that mean runoff is now significantly less due to changes in both climate and catchment land use.[5]

Figure 9: Yellow River basin, showing the pilot study area: the river downstream from Xiaolangdi Reservoir to the sea.



5 Background information on the Yellow River is drawn from Gippel, CJ, Jiang, X, Cooling, M, Kerr, G, Close, P, Jin, S, Li, L, Wang, L, Sun, Y, Pang, H, Song, R, Sun, F and Shang, H 2011, *Environmental flows assessment for the Lower Yellow River: site, assets, issues and objectives*, Yellow River Conservancy Commission, Ministry of Water Resources and the International WaterCentre, Brisbane, September.

Chapter 2. River health assessment

2.1 Importance of river health

'River health' is important. Healthy rivers provide water for drinking, for agriculture, and for industry; fish and other produce for consumption; buffers against flooding; electricity generation; and transport and recreational opportunities. As rivers become unhealthy, they lose their capacity to provide these valuable goods and services.

As a concept, river health incorporates both ecological and human values. The health of a river depends on its ability to maintain its structure and function, to recover after disturbance, to support local biota (including human communities), and to maintain key processes, such as sediment transport, nutrient cycling, assimilation of waste products, and energy exchange. In broad terms, a healthy river is a river that can sustain its ecological integrity.

Maintaining and improving river health requires an accurate assessment of the current ecological state of river ecosystems. Ideally, this assessment should involve monitoring and assessment that can:

- identify rivers or river reaches that are in poor health, or at risk of poor health
- identify the likely causes of poor river health, such as sources of pollution
- help prioritise funding for river restoration, including catchments that are most in need, and guide effective and efficient management actions
- assess the effectiveness of management actions, which is important if significant public funds are invested in improving river health
- allow for reporting on river health to improve awareness within both government and the broader community of the current condition of a waterway.

River health monitoring can involve all elements of a river ecosystem that respond at different spatial and temporal scales. These elements include water quality; the structure, abundance and condition of aquatic flora and fauna; hydrology; levels of catchment disturbance; and the physical form of the channel system. Importantly, no single variable can indicate ecological condition unequivocally and a suite of complementary variables is typically required to provide an accurate picture of river health. Therefore, water quality monitoring programs alone may be inadequate for a thorough understanding of the condition of a river over time.

In recognition of the importance of healthy rivers, the Chinese government has committed to programs that will invest billions of dollars over coming decades to reduce pollution and to improve water quality and overall river health. A comprehensive program for river health monitoring and assessment has the potential to provide valuable guidance to these investments by identifying priority regions for intervention, establishing effective and efficient management actions and strategies, and allowing ongoing evaluation of the effectiveness of management, including pollution abatement and river rehabilitation actions. The need for such a system is recognised in the ongoing efforts by various Chinese ministries and their agencies to improve the scope, quality and utility of information currently collected on river health.

2.2 Objectives and scope of river health assessments

In undertaking river health assessments in the three pilot studies, the project's objectives were to build on existing and ongoing Chinese work and draw on approaches used in Australia and internationally to:

- develop and demonstrate a method for assessing river health, including identifying indicators of river health appropriate to Chinese conditions
- assess the ecological condition of the waterways of the pilot catchments
- comment on the factors likely to be influencing river health and suitable policy responses
- demonstrate the use of a river health report card to summarise ecological condition and convey that information in a clear and simple way
- assess the suitability of the assessment methodology for application in China
- make recommendations on the development of a river health monitoring program for wider application within China.

The pilot studies adopted different methods and indicators for assessing river health. Indicators that were trialled included:

- water quality and biological indicators
- hydrological indicators
- indicators of physical form
- socio-economic indicators.

Socio-economic indicators were only considered as part of the Yellow River pilot. Socio-economic indicators complement environmental health indicators by reporting on some of the services provided to society by the river. Indicators can be developed to measure the extent the river and water managers have been successful in meeting objectives such as those related to water supply (e.g. volume, quality, reliability), hydropower production and flood control.

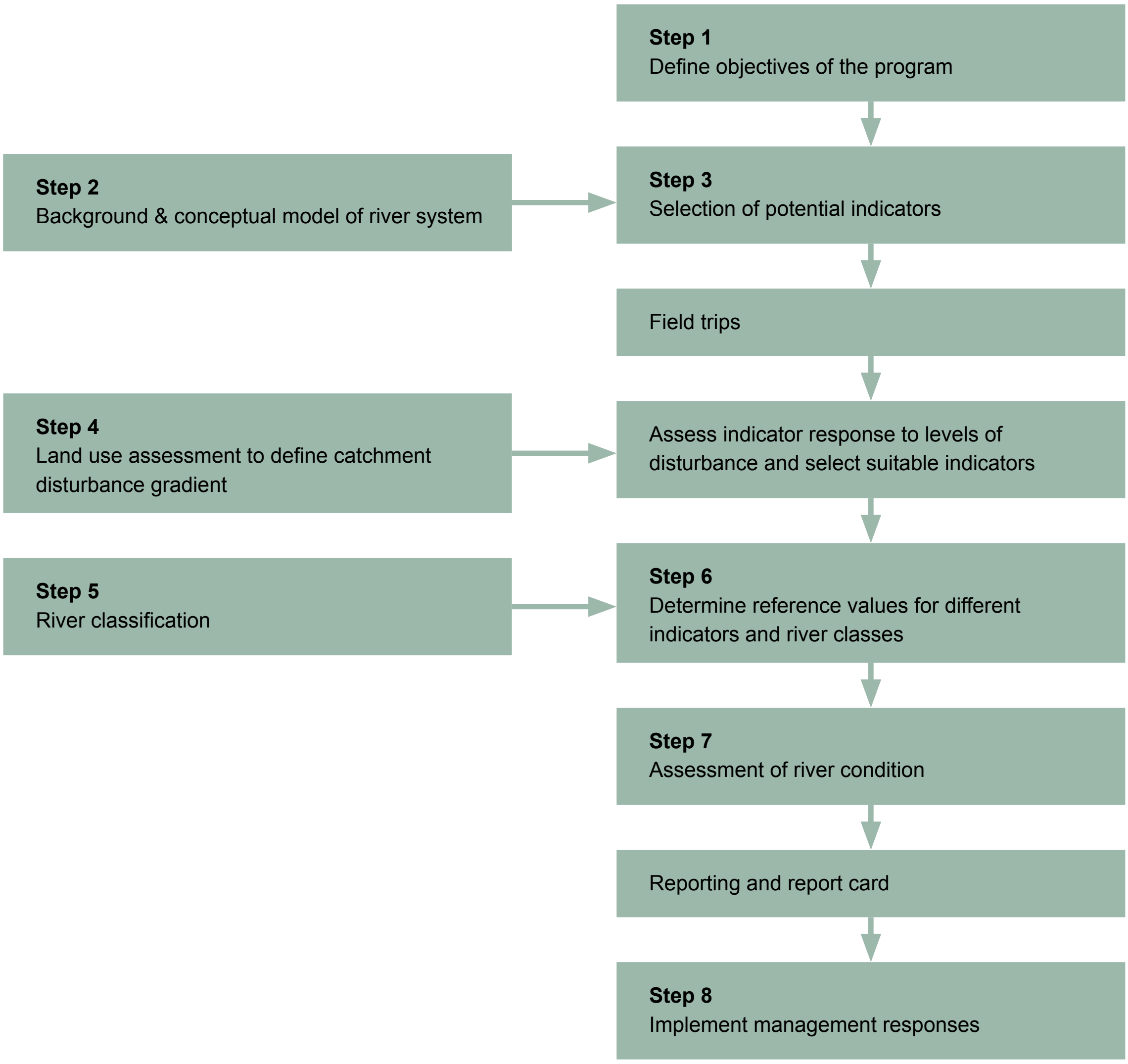
The following sections consider the approaches to assessing river health in (i) the Liao and Pearl River pilots (ii) the Yellow River pilot (iii) the use of hydrology as an indicator of river health, which was common to the three pilot studies.

2.3 Assessment methodology: Liao and Pearl River pilots

The pilot projects were aimed at identifying suitable indicators and reference values for incorporation into a routine monitoring program. To be meaningful for management purposes, the indicators and reference values should describe the environment in ways that show a predictable response to changes in river condition caused by anthropogenic factors, for example in response to agricultural development and urbanisation. This approach can allow targets to be set; if the target is not met, it is indicative of the need for management action. By comparing scores for different rivers against a reference value, locations can be ranked for overall health, to identify rivers or regions most in need of intervention, and to guide and prioritise investment to improve river condition.

The assessment method adopted in the Pearl and Liao studies generally followed the successful and well-documented approach of the freshwater ecosystem health monitoring program in South East Queensland, Australia.[6] This approach focuses on using conceptual models and objectives, quantitatively testing potential indicators against a known disturbance gradient. The key steps in the method are shown Figure 10.

Figure 10: Steps in developing an ecosystem health monitoring and assessment program.

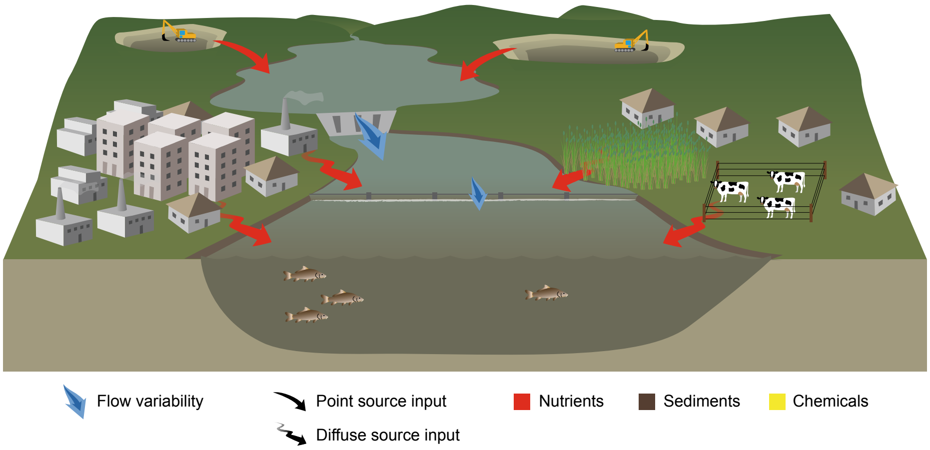


6 Bunn, SE, Abal, EG, Smith, MJ, Choy, SC, Fellows, CS, Harch, BD, Kennard, MJ, Sheldon, F 2010, 'Integration of science and monitoring of river ecosystem health to guide investments in catchment protection and rehabilitation', *Freshwater Biology*, vol. 55, pp. 223–240.

Step 1: Objectives for the monitoring program were established, based on the types of human disturbances acting on the rivers (e.g. industrial pollution); the values and uses associated with the river system (e.g. drinking water supply); and management priorities (e.g. protection of certain species or habitats, river restoration activities).

Step 2: Conceptual models were developed to identify how human disturbances are likely to affect river health and to help guide indicator selection and interpretation. An example of one of the conceptual models developed for part of the Taizi River catchment is shown in Figure 11.

Figure 11: Conceptual model for middle region of the Taizi River Basin.



Step 3: A suite of potential indicators were identified that could be used to characterise different aspects of the ecosystem. Given the trial nature of the project, it was decided to test a large range of indicator groups, including water quality, macroinvertebrates, diatoms, fish, and riparian and in-stream vegetation. The first priority was to identify the data that needed to be collected or collated, from which a large number of different indicators could be calculated. The pilot then refined this large list of indicators.

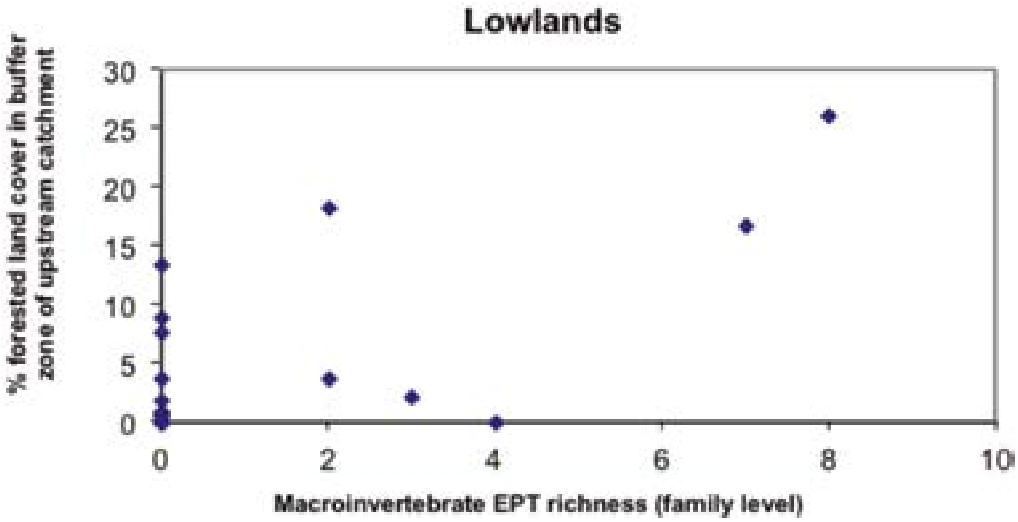
Step 4: Data was collected to support indicator analysis. In the Pearl River pilot, 25 sites were sampled in April 2010 for water quality, macroinvertebrates, fish, diatoms, riparian vegetation and physical form. In the Liao River pilot, data collected by CRAES from 70 sites during sampling in May 2009 was used.

Land use practice (level of agriculture, urbanisation, etc.) was used as the primary disturbance gradient to test the sensitivity of potential indicators. In the Pearl River pilot, the percentage cover of different land use categories was calculated using GIS software for the entire catchment upstream of each site, and within a one kilometre wide buffer area extending five kilometres upstream from each site. A similar process was undertaken in the Liao River. Water quality was also used as a secondary disturbance gradient.[7] Through this process, the degree of human 'disturbance' for each sampling site was established.

A large number of different indicators (45 in the Pearl River pilot) were tested to see if the value of the indicator at different sites changed in a predictable way based on the level of disturbance at the site (Figure 12). This process was designed to exclude indicators that are either too variable or show no clear trend along the disturbance gradient, as well as redundant indicators, i.e. those that respond the same way as other indicators.

7 Stressors to aquatic ecosystems (e.g. land use change, hydrological alteration and riparian condition) affect water quality parameters (e.g. nutrient concentrations), which in turn affect biota (e.g. fish, macroinvertebrates and algae). Therefore, water quality parameters can act as both disturbance gradients and river health indicators in their own right.

Figure 12: Example plot from the Liao pilot study, showing a macroinvertebrate indicator for each site in the lowlands, versus upstream forest cover.[8]



Step 5: Each catchment was divided into regions or zones as part of a classification process to identify homogenous river 'types'. In the Taizi River catchment, three regions (highlands, midlands and lowlands) were identified, based on the natural characteristics of the catchment. The Gui River catchment was divided based on stream order. These regions were used to establish reference values for different indicators. River condition was also assessed by region or class.

Figure 13: Classification of the Taizi River catchment into three regions.

8 The indicator is for richness of certain taxa for each site in the lowlands, versus upstream forest cover. Taxa richness increases with forest cover (i.e. less disturbance), which suggests a predictable response to changes in levels of human disturbance.

Step 6: Reference values were set for each of the indicators to establish a 'good' indicator value (i.e. the score expected for a river in good health) and a 'poor' indicator value, that is a river that did not meet the minimum required standard. These reference values were set using a combination of:

- existing Chinese standards or guidelines, such as the Environmental Quality Standard for Surface Water (GB3838-2002)
- existing international standards or guidelines, such as the Australian and New Zealand Environment Conservation Council (ANZECC) water quality guidelines used in Australia
- results from international studies
- data from the pilot study, by considering the distribution of scores across sampling sites.

This process also led to the exclusion of certain indicators, where no appropriate reference values could be established. An example of some of the indicators and reference values for the Pearl River pilot, as well as the basis for deriving the values, are shown in Table 2.

Table 2: Reference values for a subset of the indicators used in the Pearl River pilot.

					Basis of values		
Indicator group	**Indicator**	**Region**	**'Critical' threshold**	**'Very good' target**	**Chinese standards**	**International research/ standards**	**Pilot study data**
Water quality	pH	All	<6 or >9	6–9	✔		
	EC (uS/cm)	All	≥ 1500	≤ 400	✔		
Nutrients	NH4 (mg/L)	All	≥ 2	≤ 0.15	✔		
Algae	IBD	All	1–4	>16		✔	
Macro-invertebrates	EPT_Ratio (family)	Highlands	0.0–0.25	>0.45		✔	
		Midlands	0.0–0.16	>0.34		✔	
Fish	Abundance	All	<5	<20			✔
	Residual weight	All	<-0.61	>0.55			✔

At each site, a score from 0 to 1 was assigned to each indicator, using the reference values as a benchmark. These scores were then aggregated to produce combined scores for different indicator groups, sites, and regions. Scores were ranked along a scale from 'good' to 'critical'.[9]

Step 7: Based on the data analysis, an assessment was made of river conditions across different parts of the pilot catchments. River health 'report cards' were also prepared. River health report cards are brief summary documents that show the project methodology and results of the assessments, and are designed as a communication tool to present the findings of the pilot studies in an easily understood format. The report cards are prepared in addition to detailed technical reports prepared for each pilot study.

The report cards report a large amount of scientific data in a simple format. Results are reported graphically, showing results for different sites, regions, indicators, and indicator groups.

Step 8: Recommendations were made on possible management responses to address aspects of poor river health. The preliminary nature of studies limited the scope for making detailed or specific recommendations for management responses. The capacity for river health assessments to guide management decisions can be expected to improve significantly over time.

9 Note that different terminology was adopted in different pilots, based on local preferences.

2.4 Assessment methodology: Yellow River pilot

There were notable differences between the river health assessment method adopted for the Pearl and Liao Rivers, and the assessment method used for the Yellow River. The Pearl and Liao River pilot studies characterised the health of the stream network within whole catchments, while the lower Yellow River pilot study only characterised the lowland main stem of the Yellow River, which has very little local catchment.

Consequently, it was not practical to test different indicators in the Yellow River pilot against a disturbance gradient, given the small change in catchment disturbance across the lower Yellow River, together with the large number of factors likely to be influencing river health at the lower end of a large, developed river basin. The Yellow River pilot assessment did, however, follow the steps shown in Figure 10, although the indicators were not tested against levels of catchment disturbance.

Objectives and indicators were selected based on current management goals of the Yellow River Conservancy Commission, including the overarching objective of 'Keeping the Yellow River Healthy'. Four key management objectives were also taken into account and specific indicators were considered related to these and other objectives. The four key management objectives were:

1. protecting against flooding, i.e. a breach of the dikes
2. preventing the river from ceasing to flow
3. maintaining water quality within prescribed limits
4. ensuring the riverbed does not rise further.

Existing socio-economic, hydrology, water quality and physical form data collected as part of routine monitoring programs was used in the assessment. For the ecological indicators, data on fish, macroinvertebrates, and riparian plants collected by the Chinese Academy of Sciences during a 2008 survey was used. Remote sensing data was also used to assess delta vegetation.

The lower Yellow River was divided into four reaches for the assessment, based on geomorphological and hydrological characteristics and the location of key ecological assets. The reaches were used in establishing reference values and for reporting purposes. The approach taken for different indicator groups is discussed in the following sections. The indicator groups were: water quality, biological indicators, delta vegetation, physical form and socio-economic indicators.

Water quality

Water quality was assessed against the standards for two different grades of river under the Chinese national water standards - Environmental Quality Standard for Surface Water (GB3838-2002):

- **A Grade III river:** This is the official target for water quality in the lower Yellow River. It is the minimum grade required for a drinking water source and, therefore, is appropriate for assessing river health as it relates to human water use.
- **A Grade II river:** This target sets a higher standard, and is used for rivers or river reaches that provide natural habitat for sensitive and rare aquatic species, or fish and crustacean spawning areas. This grade was considered more appropriate for achieving good ecological health.

Data was analysed for the four reaches in the lower Yellow River for the period 1994–2009. The national standards cover 24 parameters, which include physical parameters (temperature); bacterial parameters (faecal coliform); and chemical parameters (pH, metal and non-metal toxicants, nutrients, and measures of oxygen balance). Some parameters were not considered in the study, notably total nitrogen and total phosphorus, where the standards were considered inappropriate given the natural characteristics of the Yellow River.

By assessing monthly data, the extent to which the target grade was achieved for each parameter, during the wet and dry seasons as well as for the whole year, was calculated.

Figure 14: Chinese water grades, arranged by classes of use, and an arbitrary aquatic health rating. S = suitable for use, and U = unsuitable.

	Drinking water			Recreation			Industry agriculture and parks					Ecological river health							
Chinese grade	**Source areas**	**1st class**	**2nd class (requires treatment)**	**Primary contact**	**Secondary contact**	**Passive non-contact**	**Aquaculture**	**General industrial uses**	**Industrial cooling**	**Agricultural irrigation**	**Irrigation of parks and created landscapes**	**National conservation areas**	**Sensitive and rare aquatic species**	**Common aquatic species**	**Fish spawning**	**Fish rearing**	**Fish migration**	**Frish winter survival**	**Arbitrary aquatic health rating**
I	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	High-very high
II	U	S	S	S	S	S	S	S	S	S	S	U	S	S	S	S	S	S	Mod.-High
III	U	U	S	S	S	S	S	S	S	S	S	U	U	S	U	U	S	S	Low-Mod.
IV	U	U	U	U	S	S	U	S	S	S	S	U	U	U	U	U	U	U	Very low
V	U	U	U	U	U	S	U	U	S	S	S	U	U	U	U	U	U	U	Very low
VI	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	No value

Biological indicators

Fish, macroinvertebrate, and riparian vegetation indicators were used to assess ecological health within the river channel. The data used was collected in 2008 as part of a river survey by the Chinese Academy of Sciences that included the four reaches of the lower Yellow River. Reach-specific reference values were derived from historical data, a literature review, and expert opinion, to provide a score on ecological condition. A total of nine indicators were selected for inclusion in the report card. Scores were assigned based on the observed/expected ratio, and with different indicators weighted based on the importance of the indicator and the quality of related data.

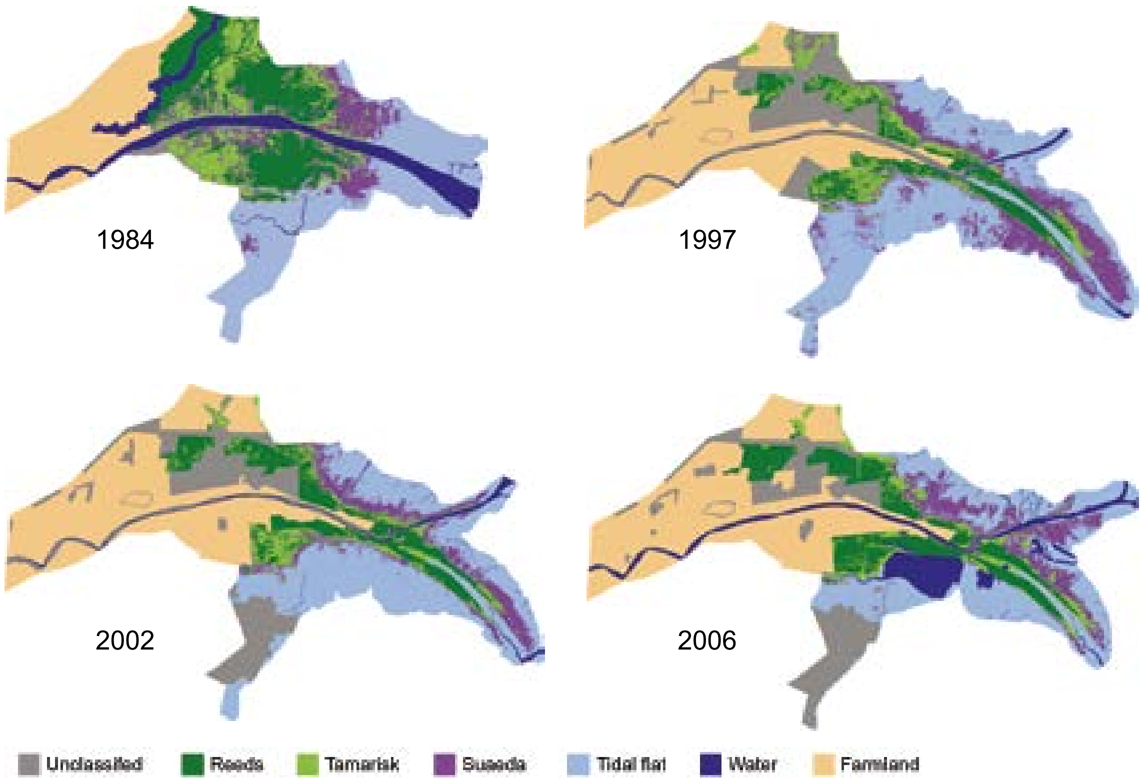
Delta vegetation

The ecological value of the internationally important wetlands in the lower Yellow River is heavily dependent on the health of vegetation communities. An index for wetland vegetation in the delta was developed through analysis of data from Landsat satellite images. The index is based on two indicators:

- the composition of the vegetation for three main wetland vegetation types (based on the extent of vegetation of greatest value to waterbirds)
- the extent of loss of wetland area to agriculture.

Both indicators were assessed relative to conditions in the year 1984.

Figure 15: Satellite images of Yellow River delta over time, showing changes in vegetation composition.



Physical form

Physical form indicators were considered that related to:

- **channel physical form** – the bankfull channel capacity, which is important for managing flood risk
- **delta physical form** – this indicator focused on the amount of sediment supplied to the annually, sediment concentrations, and growth rate of the delta area, which are important for maintaining the delta's characteristic wetland vegetation.

Socio-economic indicators

The study considered a range of social and economic indicators for the river:

- **water consumption** – based on water consumed within the basin and transferred out to other regions relative to planned or expected consumption
- **hydropower production** – based on annual electricity production versus the maximum design target for Xiaolangdi Reservoir
- **flood risk** – comprised of both storm and ice flood risk – storm flood risk was based on channel capacity (ability to retain a flood with a peak of 7,000 m^3/s), while ice flood risk was based on the longest extent of the river that is frozen and the river discharge in the ice flood risk season
- **drought risk** – based on levels of risk specified in the river's trial drought control plan
- **navigation** – based on navigable length and maximum boat weight that can be supported.

2.5 Assessment methodology: hydrological indicators

Hydrology is an important controlling variable of the health of biota in streams. Hydrology can be used to aid interpretation of ecological data, or it can be included as a component of a river health index. In regulated rivers, the hydrology is at least partly manageable, so in this situation, one potential benefit of a hydrological assessment is identifying aspects of hydrological management that can be altered for the benefit of the ecology.

Four contrasting methods to hydrological characterisation were tested:

1. The **Flow Stress Ranking (FSR)** procedure, an existing rapid method of characterising hydrological alteration, widely used in Australia.
2. The **Chinese Hydrology and Water Resources Index (HD)**, which has been proposed by MWR for a nation-wide river health assessment program as part of the early stages of a pilot program. The index comprises two indicators, the Flow Variation Degree (FD) and Satisfaction of Ecological Flow (EF). Only EF could be calculated as part of the project, because FD requires a modelled reference flow series, which was not available. The EF indicator, which comprises two scores called EF1 (for the low flow season) and EF2 (for the high flow season), is grounded in the Tenant method.
3. The **Index of Flow Deviation (IFD)**, which uses a suit of flow deviation indicators based on historical monthly flows.
4. The **Index of Flow Health (IFH)**, which uses environmental flows compliance testing as a river health index.

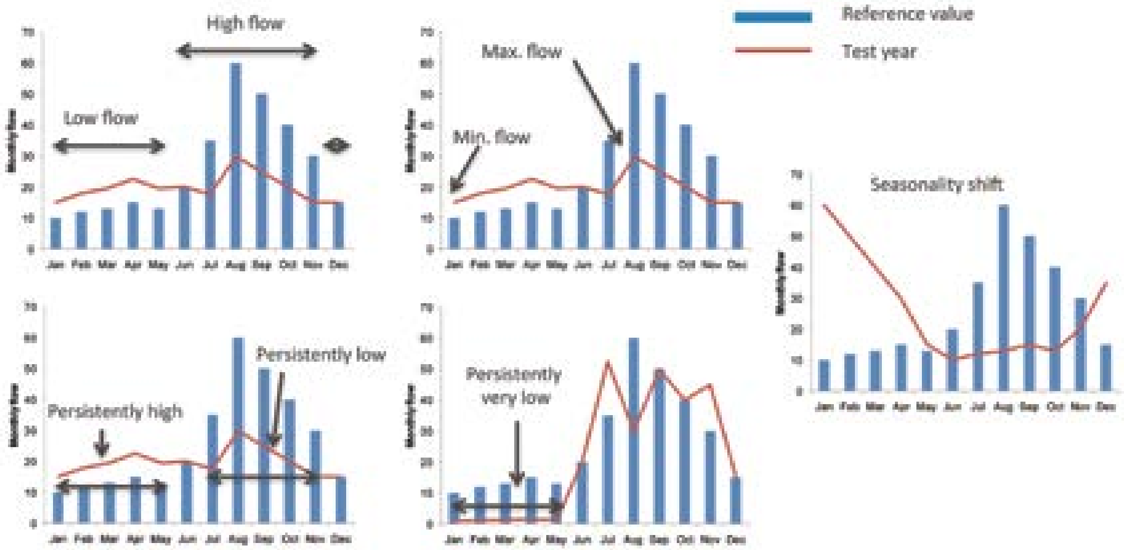
The IFD and IFH were developed specifically for the project to overcome limitations with existing methods. The following sections describe the approach used to calculate the IFD and IFH, as these methods were considered most suitable for future application in China.

The IFD and IFH methods differ fundamentally. The IFD is designed to assess the extent general hydrological parameters, thought to be either universally important (or undesirable) for maintaining good river health, have been altered from the reference (natural) flow regime. In contrast, the IFH examines whether specific flow parameters, identified through a site-specific environmental flow assessment, occur in the current flow regime.

2.5.1 Index of flow deviation

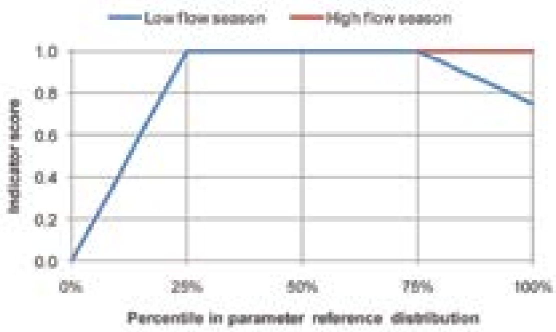
The IFD was developed as part of the project to overcome the limitations of existing rapid assessment methods (such as the FSR and HD) and the suitability of those methods for Chinese rivers. In simple terms, the index relies on a suite of eight indicators that represent different aspects of flow regime recognised as being of universal importance for river health – periods of cease-to-flow, base flows during low- and high-flow periods, high flows, and the timing or seasonality of flows (Figure 16).

Figure 16: The eight indicators that make up the IFD.



For each parameter, a score from 0 to 1 was calculated for a given year, based on the degree of deviation beyond a reasonable range of natural variability. Developing a score relies on a reference period (ideally a pre-regulation period or period of limited hydrological alteration), which is used as the basis for determining the natural variability of the eight parameters. Where the value for a given parameter falls within the 25th and 75th percentile range of the reference distribution, the value is given a score of 1, and less than 1 where the value is outside of that range (Figure 17).

Figure 17: IFD indicator scoring system.

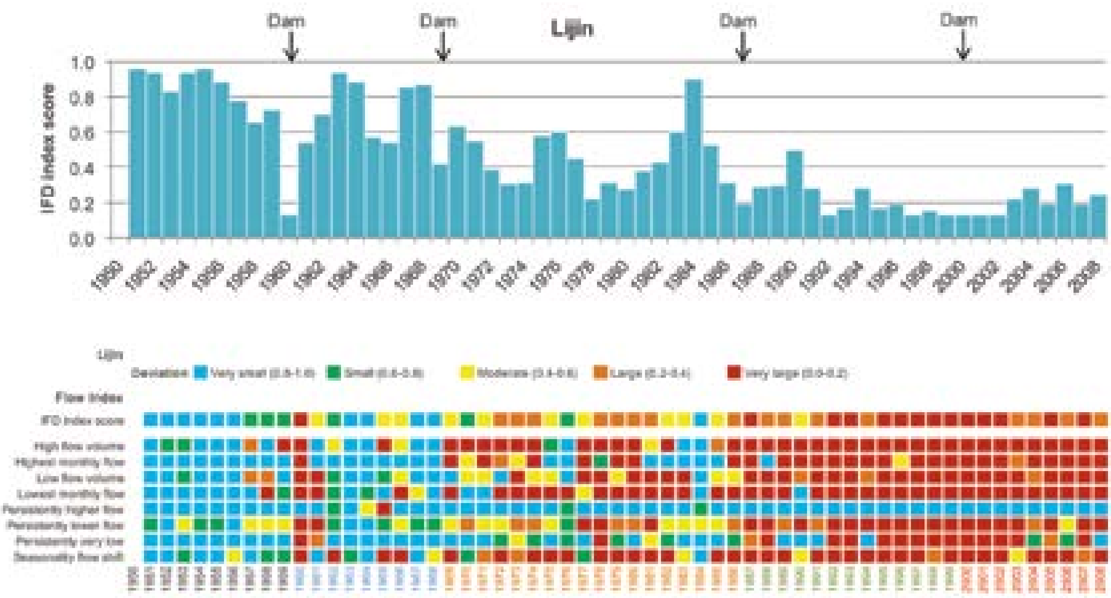


The IFD method uses monthly flow data and allows for the level of alteration to be calculated:

- for each of the eight indicators, as well as developing a combined score
- for each year that flow data was available
- for each gauging station on the three pilot rivers.

As well as scores for each indicator, a combined IFD result was also calculated. Figure 18 shows the results for the lower Yellow River at Lijin for each year between 1950 and 2008 for both the combined score and for the separate indicators.

Figure 18: The combined scores (above) and individual scores for the eight indicators (below) using the IFD at Lijin gauging station, lower Yellow River.



A software tool that automatically calculates scores using the IFD method has been developed as part of this project and is available for free download from www.watercentre.org.

2.5.2 Index of flow health

In contrast to the IFD, the IFH assesses the extent to which specific flows or flow patterns – identified through a site-specific environmental flow assessment – are being achieved. The IFH method thus requires an environmental flow assessment to be undertaken in the catchment first. The project used the results from the detailed environmental flow assessment of the lower Yellow River, described in section 3.3, and a relatively rapid environmental flow assessment that was completed for the Taizi River.

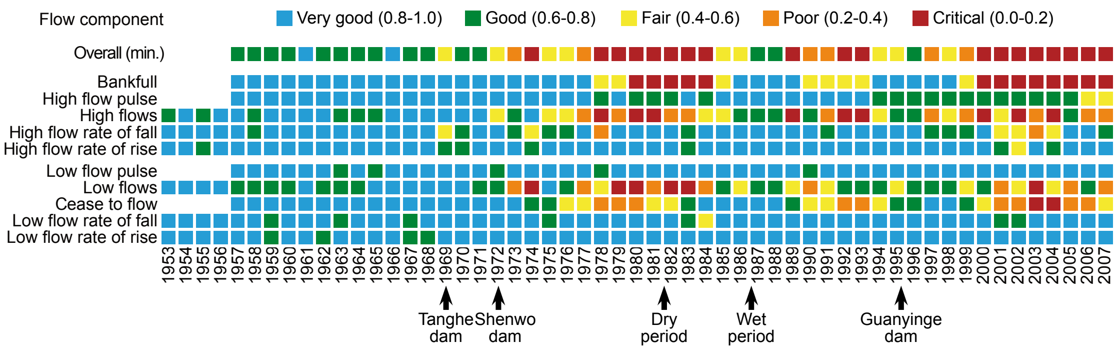
In simple terms, the environmental flow assessments identified a detailed list of flow objectives associated with outcomes in respect of geomorphology, macroinvertebrates, vegetation, and fish. These flow objectives were linked to different elements of the flow regime – low flow, high flow, pulses, and overbank flows. The frequency, duration, and timing of the required flows was also specified. To assess compliance with these objectives, and therefore river health via hydrology, the environmental flow objectives were reduced to a suite of core flow components: those related to bankfull flows, low and high flows, pulses, and rates of rise and fall.

Compliance means the frequency with which environmental flow components appeared in the historical flow time series, relative to the frequency recommended for implementation, designed to achieve the agreed level of river health. As the environmental flow objectives are specified in multi-dimensional terms of magnitude, duration, annual frequency and inter-annual frequency, the IFH method uses a sophisticated form of spells analysis to determine the compliance of each flow component. The event-based environmental flow components (pulses and bankfull) require a minimum inter-annual frequency. The IFH score takes this frequency into account by measuring the occurrence of the event in the year, plus in the number of previous years that sum to the period over which the inter-annual frequency was specified. For example, for the lower Yellow River the inter-annual frequency was specified for a five-year period. The event-component scores for each year contains a 'memory' of the occurrence of the events in the previous four years.

A score from 0 to 1 was calculated for each component, some of which were made up by multiple sub-components. Each score was reduced to one of five categories, with those ranging from 'Very good' (>0.8) to 'Critical' (<0.2).

Scores for each core flow component was calculated for each year of data available (approximately 50 years for the Yellow River), and each gauging station. The results were colour-coded for the level of compliance with desired flow regime for each flow component, with blue showing 'very good' compliance, and red indicating 'critical'.

Figure 19: Results for Liaoyang gauging station on the Taizi River (above) for period 1953–2007, and for Lijin gauging station on the Yellow River (below) for period 1950–2008, showing the level of compliance with the environmental flow objectives.



2.6 Results of river health assessments

International experience shows that the process of developing a river health monitoring program can take up to a decade and cost tens of millions of dollars. The work undertaken in this study is a small, preliminary, but important step in that process.

It is challenging to make robust conclusions on river condition with an initial investigation. The natural variation in indicators represents an important constraint on river health assessments, especially when they are based on preliminary data sets, or on datasets with limited spatial and temporal resolution.

Establishing suitable reference values is a particular challenge when first implementing a monitoring program. Refining reference values to accurately reflect the local conditions generally depends on the accumulation of additional data and an understanding of how they naturally vary. As a result, setting initial reference values for river health indicators is inherently difficult, and in the early stages of investigation reference values are likely to include a level of uncertainty. Over time, the outcomes of future river health assessments will improve as larger data sets become available, the local aquatic conditions are better understood, and reference values are refined.

This section includes a brief summary of the results of the three pilot assessments. As with all other aspects of the project work, more detail on the findings is available in the various technical reports (see www.watercentre.org).

Yellow River pilot

The current environmental flow practice in the Yellow River is similar to the low-risk environmental flow regime recommended by the project (see section 3.3). As a result, compliance with the flow regime is fairly high, with a notable improvement over the last decade due to improved regulation of sediment and water resources. The main limiting factor for river health related to hydrology appears to be the loss of high flows, and the benefits they bring to the delta and by inundating wetlands within the river's dikes.

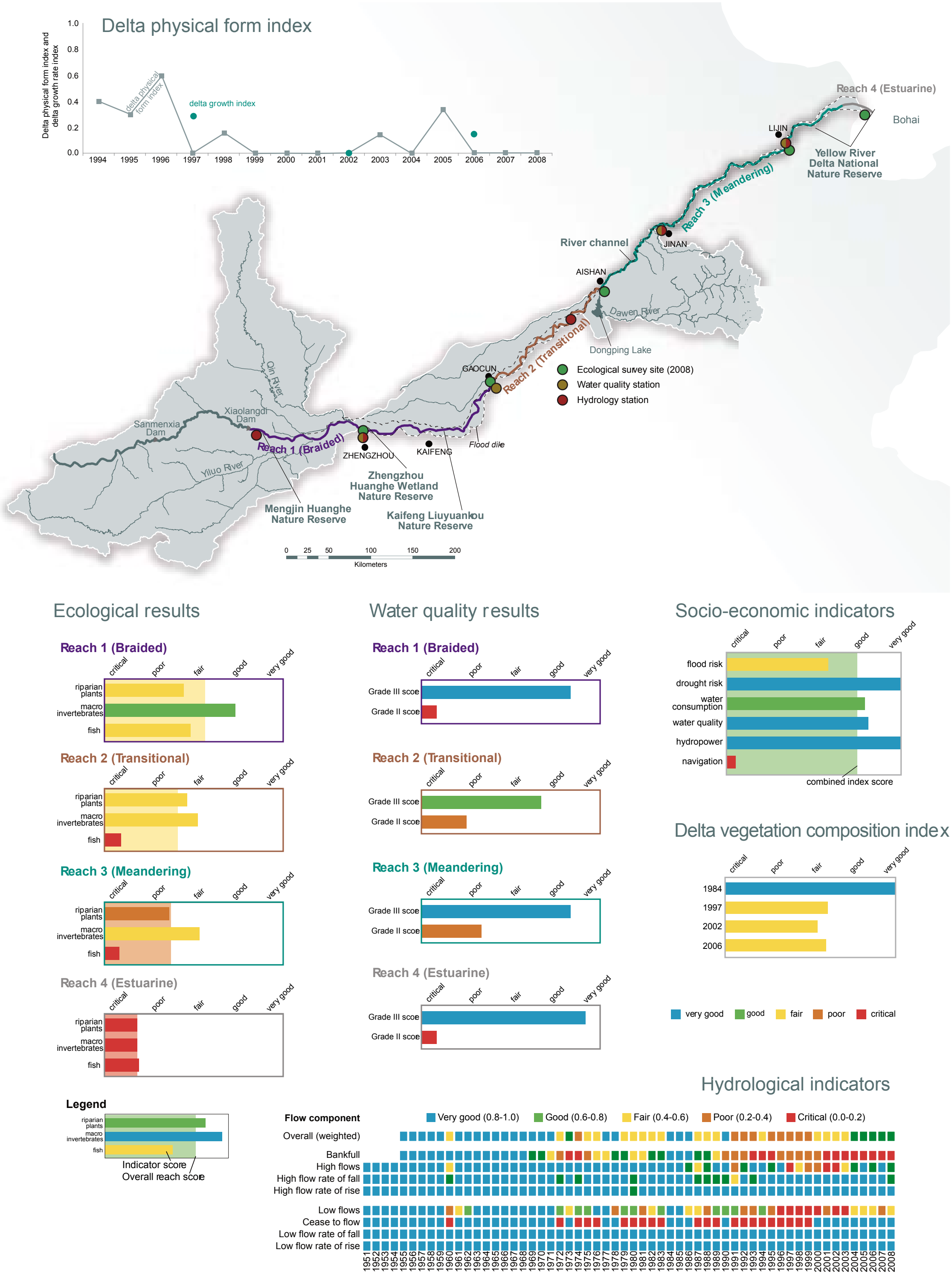
The combined environmental river health index scores suggested that hydrology was not, however, the main limiting factor to ecological health of the lower Yellow River. It appears more likely that water quality limits the ecological health. This is despite the fact that water quality is generally within the standards for a Grade III river – the MWR target for the river. This reflects the fact that the target grade, while suitable for supplying water for human use (after treatment), is not conducive to good ecosystem health. For 2008, the most recent data available, the results suggest oxygen balance, bacteria (faecal coliform) and nutrients are the limiting factors to river health among the various water quality parameters.

The results do show enormous improvements in water quality and hydrology since the late 1990s. It may take some time for these improvements to be reflected in improved biotic health scores, which were generally low.

The health of the Yellow River Delta is at risk of low sediment supply (a lot of sediment is needed to continually expand the delta) and encroachment of farmland into wetlands, although artificial watering has led to expansion of areas of open water and reed, which are important for dependent water birds.

The work on social indicators was novel, and while the results should be regarded as preliminary, it suggested ways of quantifying some of the important social values provided by the river. The indicators showed an overall high level of social value provided by the river.

Figure 20: Summary of results from the health assessment of the lower Yellow River.



Liao River pilot

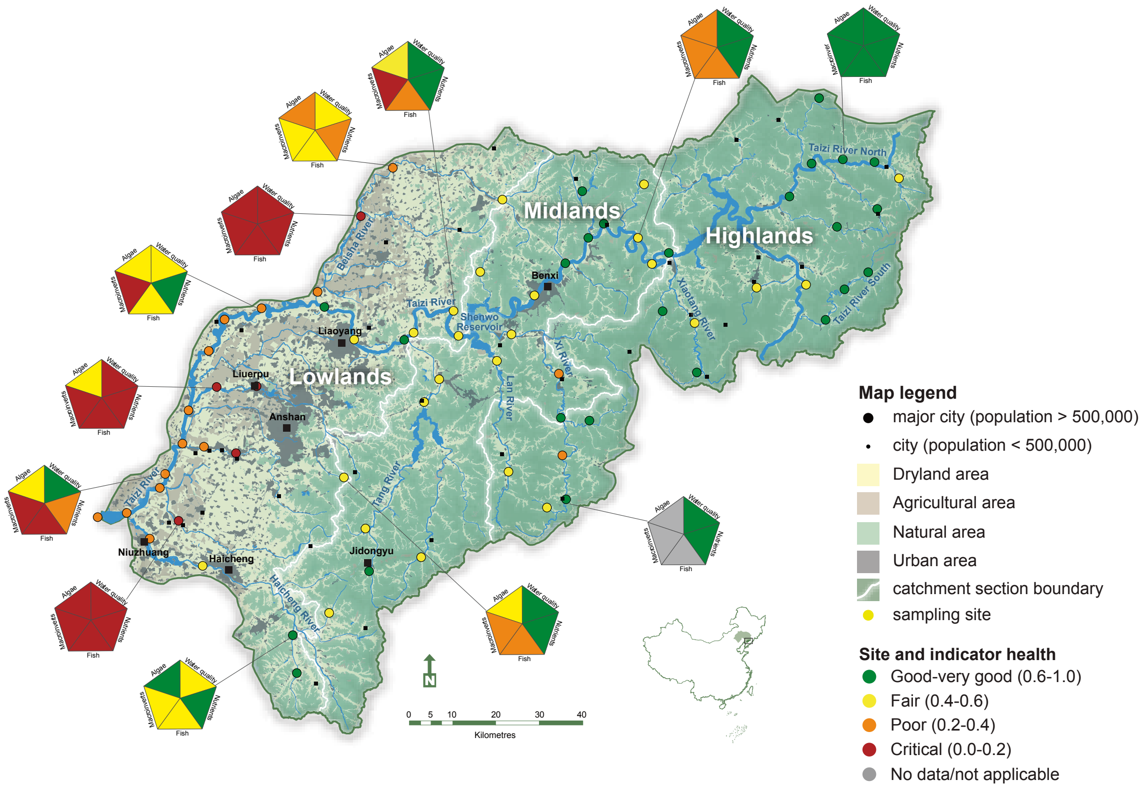
The results of the study suggest that the health of the Taizi River has been compromised across the entire basin, with river health in the lowlands assessed as being in poor to critical condition and only two sites in the basin considered to be in a state of 'excellent' health. Indicators such as those for nutrient levels and fish species richness across all regions of the catchment are considered to be at unacceptable levels for healthy river systems.

The catchment appears in better ecological health in the upper catchments, with deteriorating river health in the lowlands. This trend reflects the relative intensity of human activity within the catchment. Pollution from urban and industrial sources is clearly having an impact on water quality and river health.

Many of the biological indicators appear to reflect a poorer level of health than the water quality indicators. This is likely to be because biological indicators tend to be better long-term integrators of ecosystem condition and stress, whereas water quality indicators tend to exhibit short-term responses to individual disturbance events and only reflect the condition at a single point in time, making them statistically unreliable. The results also suggest that the poor condition of the riparian zone (as a result of the severe degradation of riparian vegetation) is having a strong and negative effect on the aquatic biota. The results also demonstrate the negative impact of flow regulation on river health. This is most evident in the midlands, where scores downstream of the major reservoirs are generally lower than those upstream.

The results for the Taizi River are summarised in Figure 21. In addition to the initial 70 sites sampled in the Taizi, a further 175 sites were subsequently sampled across the Liao trunk stream, the Taizi River, and other tributaries. The condition of these sites was assessed using the same indicators as used in the initial pilot work. The results are shown in Figure 22.

Figure 21: Summary results from the river health assessment in the Taizi catchment, showing overall scores for each sampling site (represented by colour-coded dots) and scores for each indicator group at selected sites, using multi-coloured pentagons.



What makes up the pentagon?

Each pentagon presents the river health score for each of the 5 different indicator groups sampled at an individual site. The scores for each indicator in a group are aggregated to give a single group score. The group score is indicated by the colour of the relevant section of the pentagon: a section that is green represents a score of 0.6 to 1.0 (good to very) while red indicates a score of 0.0-0.2 (critical).

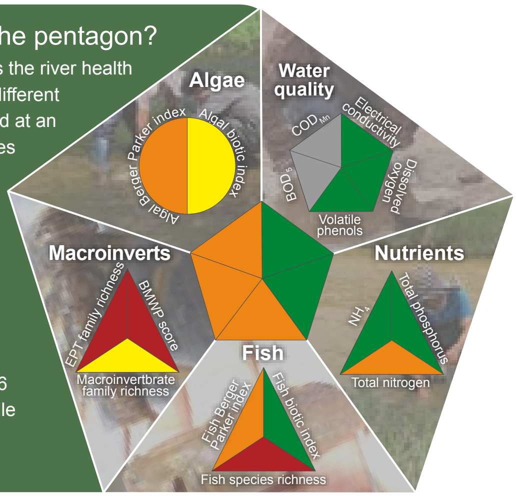
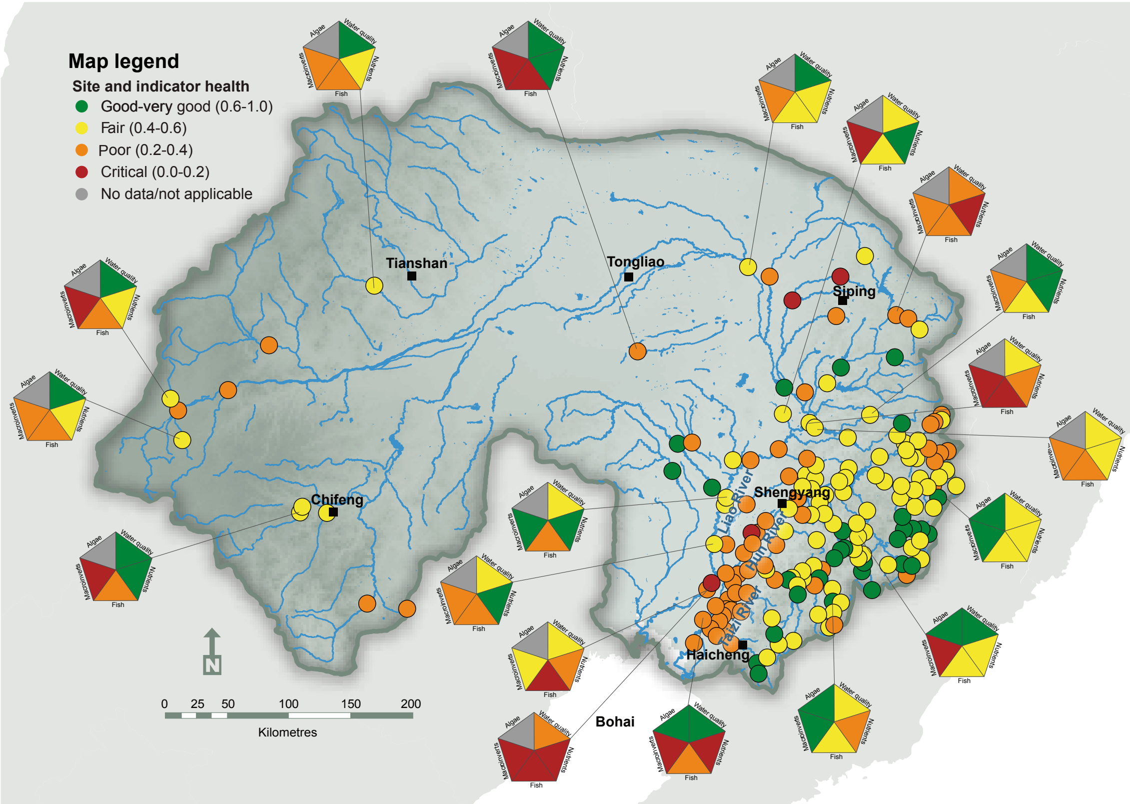


Figure 22: Results of the river health assessment for the Liao River basin, incorporating sampling sites outside the original pilot study site.



Pearl River pilot

The study suggests that the health of the Gui River is compromised in areas with intensive urban and agricultural development, but most sites were in relatively good ecological condition. Water quality was generally found to be good, although concentrations of nitrogen increased in agricultural and urban areas. The catchment appears in better ecological health in the upper catchments.

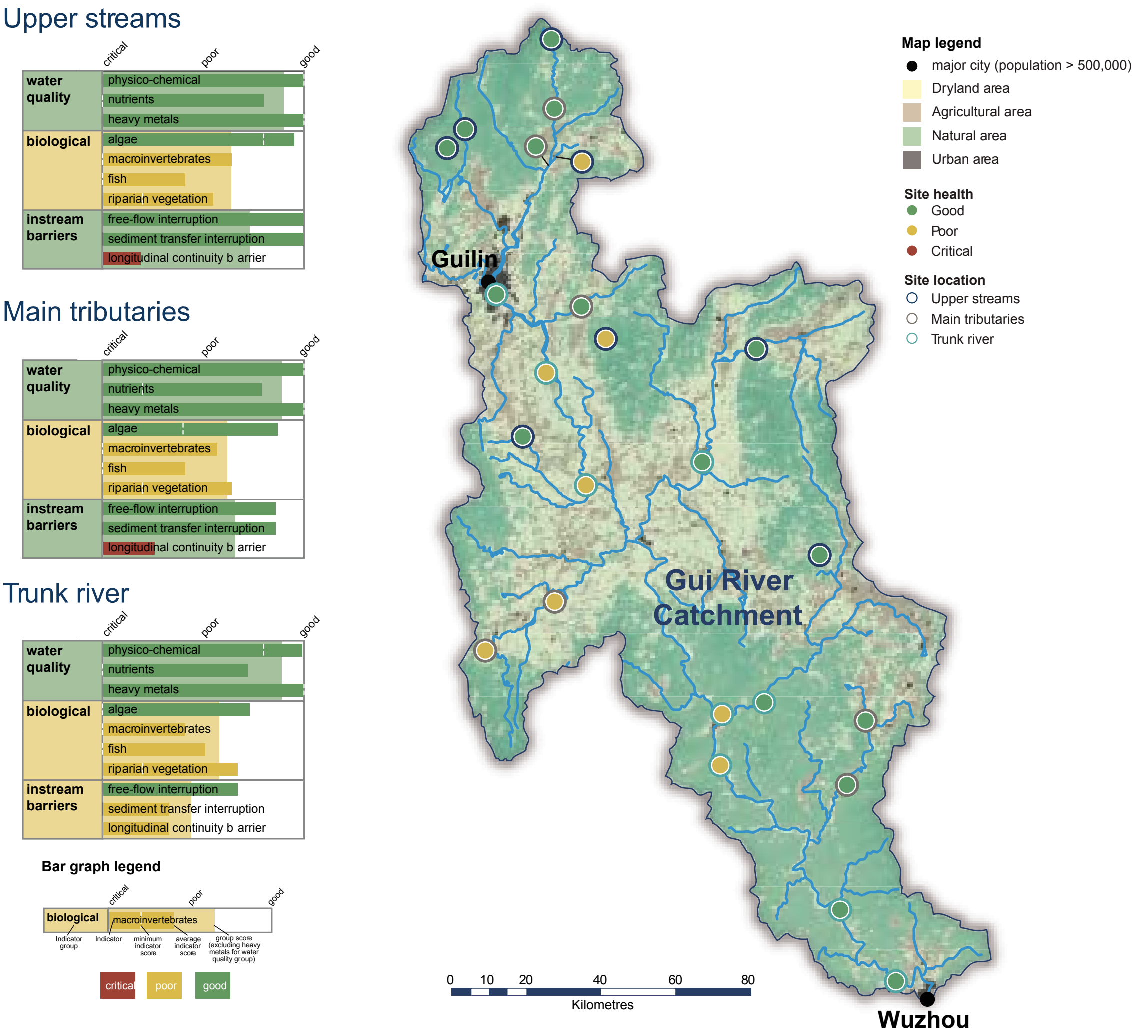
The biological indicators suggested a poorer level of health than the water quality indicators. In particular, algae, invertebrates and fish indicators suggested some sites were in ‘poor’ to ‘critical’ condition.

Biological indicators showed responses to land use disturbance at the buffer-scale (the strips of land along each side of the river) as well as catchment-wide land use, although the results were not always consistent. With only a small sample size, it is difficult to draw firm conclusions about the relative influence of these two scales. At the local scale, indicators of riparian condition highlighted the poor condition of riparian zones at a number of sites (both in terms of width and degree of fragmentation), which will have a direct influence on the in-stream scores due to the reduced buffering capacity against neighbouring land use.

The assessment of hydrology, based on monthly data, suggested stream flow patterns have not been substantially affected by reservoir construction. Anecdotal evidence suggests that low flows during the dry season have been an issue in recent years. These periods of extreme low flow may be too short to be captured by monthly data. Their impacts may need to be examined via more detailed studies.

While not well reflected in the limited data collected, longer-term trends in fish diversity in the catchment raise questions about factors relating to the health of fish assemblages.

Figure 23: Summary results from the river health assessment of the Pearl pilot (Gui River catchment).



2.7 Conclusions from the pilot studies

The pilot studies were preliminary steps in a long process of developing a national, routine river health monitoring program for China. Across all three pilot studies, the limited number of sites sampled and the limited data sets pose challenges for making robust conclusions about the health of these rivers. The lack of suitable reference values due to an absence of existing guidelines and limited data also creates challenges. Further monitoring, both within the pilot catchments and elsewhere in China, will contribute to filling this knowledge gap.

These factors limit the scope for making recommendations about the most suitable indicators for future local and national application. However, the results do provide a starting point, and the following sections discuss the key findings about the suitability of different indicators based on the pilot work, as well as some of the further work required in this field.

Indicators responding to catchment disturbance

The approach of assessing the results for different indicators against various disturbance gradients identified a number of indicators that appear to respond to changes in catchment disturbance and, therefore, may be suitable a river health assessment program.

Indicators should respond predictably to changes in the catchment and to changes in river health. Importantly, it cannot be assumed that indicators that are suitable for one river basin will necessarily be suitable in another location – local conditions can affect indicators' responses and the suitability of different indicators. Ideally, indicators should be tested for their responsiveness within different settings.

The Pearl and Liao River pilots examined a range of river health indicators and their applicability to Chinese rivers. Broadly, the analyses confirm that each of the indicator groups provides useful information and that, in general, indicators derived from international experience have also proved to be effective in China. Table 3 lists those indicator groups trialled as part of the pilot studies in the Liao and Pearl Rivers that responded to the level of catchment disturbance.

Table 3: Indicators showing a response to catchment disturbance in the Liao and Pearl pilot studies.

Indicator group	Indicator
Water quality	Heavy metals
	Nutrients
	Physico-chemical indicators
Macroinvertebrates	EPT species richness
	Biological Monitoring Working Party (BMWP) (UK)
	Total species richness
	Biotic indices (US)
	SIGNAL (Australia)
Fish	Species richness
	Fish Index of Biotic Integrity (IBI)
	Size distribution
	Presence/absence of migratory species
Algae (diatoms)	Biological Diatom Index (IBD) (Europe)
	Specific Pollution Sensitivity Index (IPS) (Europe)

Several indicator groups require refinement before they can be more widely adopted in China. For example, while algae and macroinvertebrate indicators showed predicted patterns, more widespread adoption would need to be accompanied by the devel opment of scoring systems based on local data rather than using scoring systems adopted from overseas schemes. These issues are discussed in the following sections.

Use of biological indicators in large river basins

The approach of testing indicators against a disturbance gradient was not applied in the Yellow River pilot due to the nature of the pilot site, the lower reaches of a large river basin. Biological indicators were selected instead based on expert opinion and considering the availability of data and suitable reference values. Based on these criteria, the indicators shown in Table 4 were adopted. For future monitoring programs, in the absence of a disturbance gradient or sufficient data to test the relationship between a wide range of biological indicators and other data, standard and commonly used indicators should be selected.

Table 4: Biological indicators identified as suitable for use in the Yellow River.

Indicator-group	Indicator
Fish	Total species
	Piscivore species
	Migratory species
	Freshwater species (reach 4 only)
	Native species
Macroinvertebrates	Total species
	Number of functional feeding groups
	Total density
Riparian plants	Total species

Use of hydrological indicators of river health

The IFH generated an ecologically meaningful annual hydrological health score (with sub-component scores showing the detail for various environmental flow components). This approach requires that an environmental flow assessment is carried out first. Applying the IFH would realistically be limited to those places where the necessary data (ideally daily hydrological records) and resources are available to make such an assessment.

The IFD scores represented a reasonable indicator of the pattern of gross change in flow volume associated with regulation impacts, and also with periods that are naturally very wet or dry.

The IFD and IFH indicators (reported as annual scores) were significantly correlated, which suggests that the IFD could be an ecologically relevant indicator of hydrological alteration. As the IFH requires a greater effort than the simple IFD, a practical approach could be to use the IFH for the main stems of major rivers and other priority areas (such as those with high levels of development or areas of high conservation value), and apply the IFD elsewhere.

The software tool – called FlowHealth – calculates IFD scores using monthly flow data. The tool allows the index to be calculated quickly and simply for any river for which the necessary flow data is available.

The advantage of analysing and presenting the history of hydrological change, rather than limiting the analysis to the year being assessed, is that the degree of hydrological change can be placed within the perspective of past phases of change and recorded or remembered ecological responses. Also, the recent past years, if they were naturally notably wet or dry, may have had an impact on the expected ecological condition, regardless of disturbance.

In streams that are not impacted by major dams, their hydrology may have been modified by direct extraction of water, farm dams, altered land use or climate change. Separating the impacts of these changes on river hydrology requires a major modelling effort (catchment-scale, rainfall runoff and water accounting models) that in China has been limited to modelling of reference hydrology at key sites. Expansion of this modelling work would be a worthwhile undertaking. The benefits would include improved understanding of catchment hydrology, and the ability to test scenarios as an aid to integrated catchment management. Also, modelled hydrological data is preferred over historical records for assessing hydrological impacts of water resources development.

Riparian and in-stream vegetation as an indicator of river health

While assessments of vegetation condition often involve more detailed data collection incorporating structural complexity, diversity, recruitment and the presence of invasive species, it was not practical to incorporate these measures into the pilot projects due to limited time and expertise across the project team. Instead, the project focused on simpler measures.

In the Pearl and Liao River pilots, the approach focused on the likely buffer capacity of riparian zones. While the influence of buffer width and continuity varies greatly, it is still appropriate to use measures of buffer width to identify sites where buffers are very narrow or completely absent. An additional advantage of the measures used is that they can be assessed directly in the field or via remote sensing. Measures assessed via remote sensing would allow the assessment to be undertaken over a larger scale. For these pilot sites, Google maps imagery, which is widely available, did not provide sufficient resolution, but other sources of imagery may exist.

In the Yellow River pilot, Landsat satellite images were used to assess changes in vegetation composition over time. This approach depended on an understanding of the relative importance of different plant species in contributing to ecological health. The approach adopted produced a result that was consistent with most of the scientific literature on the health of the delta over time.

The results indicated that Landsat satellite data was suited to routine, cost-effective assessment of wetland vegetation health in the Yellow River Delta but, at this stage, the procedure is not fully automated. Further technical work might be able to increase the level of automation of the procedure and reduce subjectivity and processing time required. Also, while the resolution of Landsat images proved suitable for a large area like the Yellow River delta, it was deemed too coarse for assessing riparian vegetation along the river channel.

One aspect of vegetation that was not fully considered in the project was in-stream macrophytes, as this indicator proved too unreliable due to surveys being done at a time of year when macrophyte cover is at a minimum. Nuisance levels of aquatic macrophytes are, however, often associated with high nutrients levels. In China, many common floating macrophytes are invasive and pose a threat to native species diversity, can alter the structure and function of river ecosystems, can clog irrigation channels and ponds, can impede navigation, and provide habitat (stagnant patches of water) for breeding disease vectors like mosquitoes and flies, which can pose a threat to human health. The issue with in-stream macrophytes as an indicator is the substantial variation in abundance through the year, with proliferations of macrophytes generally occurring during the warmer months, which has important implication for sampling. While the project was not able to demonstrate techniques for assessing in-stream macrophytes, they should not be ruled out for incorporation into future assessments.

Table 5. Suggested indices to rapidly assess riverine vegetation condition.

Indicator	Measure
Riparian vegetation	Vegetated buffer width
	Vegetation buffer continuity
	Composition (where relative importance can be identified)
In-stream vegetation	Cover of free-floating nuisance/invasive taxa

Physical form indicators of river health

The YRCC management objectives for the lower Yellow River emphasise maximising channel capacity, lowering the bed level, and transporting sediment out of the river channel system. The main objective of these goals is to reduce flood risk, although there is also a benefit provided in supply of sediment for maintaining expansion of the delta. The Yellow River pilot adopted an approach to assessing physical form that related explicitly to these objectives: channel capacity and delta growth.

Four physical form sub-indicators were evaluated: bankfull channel capacity flow, annual sediment load, high-flow event sediment concentration, and delta growth rate. These indicators provided useful information on the state of the river, using data that is already routinely collected. These physical form sub-indicators should be considered for inclusion in any future monitoring program for the Yellow River. Given that they relate to issues that are specific to the Yellow River, they are not universally applicable to other rivers.

Some physical form variables were measured in the Gui River pilot study, mainly for the purpose of developing suitable methods for assessing physical form. Insufficient data were collected during the pilot study to allow calculation of physical form index scores or to enable proper evaluation of the indicators. Table 6 shows the indicators identified as potentially suitable for adoption in future river health monitoring programs. It is recommended that full data sets[10] be collected in the pilot catchments, followed by indicator evaluation.

Table 6: Possible physical form indicators.

Indicator	Measure
Direct disturbance of physical form	Presence/absence of sand/gravel extraction in the channel
Variability of channel shape and bed material	Mean of five channel dimension and bed particle size variability variables
Variability of channel planform	Sinuosity
Relative bank stability	Derived erosion resistance score based on bank material and riparian vegetation cover

A more expansive set of physical form indicators has been developed as part of the *Draft National River Health Assessment Guidelines* prepared by the project. This expansive set includes indicators related to longitudinal and lateral connectivity (i.e. related to in-stream barriers), and a sediment risk index, which is based on catchment disturbance.

Any approach to using physical form indicators should not rely on 'rapid visual assessment' to rate the condition of the river channel. Experience in Australia suggests that most physical processes cannot be reliably assessed visually, and even when visual clues might be potentially useful, the wide variations in assessment made by different people renders the results of such an approach unusable at a national or even regional scale. Alternative approaches include:

- quick field assessments to measure basic channel parameters (bank height, width, etc.) to establish a general understanding of channel variability based on the concept that high variability is generally positively related to high ecological river health
- focusing on specific threats to physical form and riparian habitats, such as indicators related to levels of gravel extraction, lining of the channel banks, and farming right to the edge of the river
- remote sensing and aerial photography, which is now being broadly applied in the Murray Darling Basin and elsewhere in Australia.

Water quality indicators

Existing Chinese water quality standards (GB3838-2002) were used as the basis for assessing river health based on water quality, although different approaches were adopted in different pilot studies. This standard prescribes different limits for different parameters, based on the class of river (see Table 7).

10 As per recommendations in Gippel, C.J., Catford, J., Bond, N.R., Zhang, Y., Qu, X., Kong, W., and Liu, W. 2011. River health assessment in China: development of physical form indicators. ACEDP Australia-China Environment Development Partnership, River Health and Environmental Flow in China. The Chinese Research Academy of Environmental Sciences, the Pearl River Water Resources Commission and the International WaterCentre, Brisbane, September.

Table 7: Chinese water quality grades, according to GB3838-2002.

Grade of water use	Description of water use
I	National conservation reserves, water source protection zones
II	Drinking water 1st Class; natural habitat for sensitive and rare aquatic species; fish and crustacean spawning; fish rearing
III	Drinking water 2nd Class (treatment required); sanctuaries for common aquatic species; fish survival in winter; fish migration; aquaculture; contact recreation
IV	Industrial use; active non-contact recreation
V	Industrial cooling only; agricultural irrigation; ordinary (low conservation value) landscape irrigation; passive recreation
VI	Not suitable for any purpose

In the Pearl and Liao River pilots, water quality data was collected during the field visits. The results for each parameter were scaled between 0 and 1 (critical to excellent) using reference values derived from the national water quality standards. The standards for a Grade I river were used to set the target values (a score of 1 or 'excellent'), and Grade VI values were used to define what would be a 'very poor' or 'critical' score (a score of 0).

In contrast, the Yellow River pilot relied on historic water quality data collected as part of routine monitoring programs. This approach allowed consideration of a longer time-series of data. The data was assessed against two separate standards: requirements of a Grade III river (the existing management target) and those of a Grade II river (considered by the project to be more appropriate for maintaining good ecological health). Scores were assigned to different parameters or groups of parameters based on the amount to time the relevant standard was achieved. The project considered compliance on a monthly, seasonal, and yearly basis. This approach was adopted, in part, because raw data on water quality was not available – only information on the extent to which different grades had been achieved could be accessed.

Both approaches have merit. The Liao and Pearl approach provides greater information on the actual values of different water quality parameters. The Yellow River approach is primarily a compliance test, and is appropriate for assessing the extent certain management objectives have been achieved. This approach can be used where raw data is not available, although it may not be a constraint for future programs operated by government water and environment agencies.

Information on water quality is already routinely collected across China and presents a ready source of data for assessing river condition. There is scope to improve on the existing national water quality standards, as they relate to river health. The standards have been developed to address requirements for a range of different water uses, and it would be appropriate to develop standards that specifically relate to river health.

Finally, any national system will need to recognise the natural variation in water quality due to local conditions, which can mean that certain indicators or standards are not appropriate for a particular river. For example, total phosphorus was excluded from the assessment of the Yellow River. The extremely high phosphorus levels that occur naturally in the Yellow River mean that the river would fail to meet the national standards, despite the fact that the phosphorus load is associated with particulate matter, is not biologically available, and is unlikely to increase the risk of eutrophication. Any national river health guidelines will need to allow for the selective exclusion or adjustment of different water quality indicators and reference values to reflect local conditions.

Socio-economic indicators of river health

While socio-economic indicators have not traditionally formed part of river health assessments in Australia, their inclusion provides scope to assess and highlight the various benefits that people and communities derive from rivers. This may in turn increase understanding and recognition of the value of healthy rivers.

The pilot study in the Yellow River identified six indicator groups as suitable for possible inclusion in a river health assessment. The indicator groups relate to (i) flood risk (ii) drought risk (iii) water consumption (iv) water quality (v) hydropower production (vi) navigation. Recreational values were also considered, but were not included due to a lack of data.

For many Chinese rivers, some or all of these indicator groups are likely to be relevant measures of the social services provided by the river, and there are likely to be both existing management targets and data on actual performance, making the inclusion of these indicators relatively simple.

While there are clear benefits of including this f information in a river health assessment, it would be preferable to clearly distinguish between scores related to the physical and ecological condition of the river, and those that relate socio-economic outcomes, rather than attempting to combine the two into a single index.

Further steps in the pilot catchments

Further work is needed to refine the method applied during the pilot studies to improve the quality of the results, particularly before the indicators trialled can become the basis for a routine monitoring program. It is recommended that the following research topics be considered as part of any future monitoring:

- Confirm initial results of the pilot assessments and refine the set of recommended indicators by repeating some of the work done in correlating indicator values with levels of catchment disturbance.
- Assess seasonal variability by assessing whether the correlation between indicator scores and catchment disturbance is different at different times of the year (the current study relied on a single sampling undertaken during spring). It is possible that some indicators are more or less suitable for assessing river health at different times of the year.
- Refine existing water quality guidelines (including developing Chinese standards for total nitrogen (TN) in rivers and streams) and river health target levels using a load-based approach for indicators such as nutrients and sediments.
- Investigate linkages to down-stream ecosystems such as estuaries and coastal zones. This investigation may include the modelling of nutrient and sediment budgets and their likely impacts on estuarine and marine ecosystems.

In addition to the further development of the river health science, a shift towards a routine monitoring program requires significant investment of time and resources to develop the necessary systems and human capacity. A considered approach to these issues is important to ensure the program will be effective and sustainable over the long-term.

2.8 Recommendations for a national river health monitoring program

The work undertaken during the project, together with international experience, provides a number of lessons that should be considered in the implementation river health monitoring programs in China, particularly in the development of a national program.

Setting clear objectives for river health monitoring

With a clear vision statement, it is possible to identify the assets and values that reflect that vision, and the water quality and ecosystem health objectives that protect those values. Without a clear vision, a monitoring program will be poorly defined and unlikely to lead to improvements in river health. It is important at the outset to be clear on the purpose of monitoring and what it is designed to achieve:

- Is the monitoring to protect important environmental assets and values (e.g. conserve wetlands)?
- Is the monitoring to maintain ecosystem goods and services (e.g. clean drinking water, productive fisheries)?
- Is the monitoring to see if a particular action, like an environmental flow, achieved what was intended?

Having an agreed vision statement – and knowing what it means – can drive the development of a monitoring program. For example, if the vision is a 'Healthy Yellow River', the objectives should describe what this means. For example, whether in (say) 10 years time the river will have more fish, or more species of fish, or whether the water is safe to drink or swim in. Answering these types of questions will help determine appropriate indicators and thresholds of concern for inclusion in the monitoring program.

Selecting the best indicators

The selection of potential indicators should be guided by their relevance to important environmental assets and values, and their likely response to different threatening processes.

Ongoing pilot studies in China present an opportunity to improve on the initial list of indicators identified during the project. This process should include an assessment of whether or not there is a relationship between the different indicators or indices and disturbances known to affect river health (e.g. changes in land use, pollution discharge, poor water quality).

This group of indicators can then be refined by checking for any redundancy across the different indicators, excluding redundant indicators from future monitoring. An assessment of the cost-effectiveness of different indicators should also be undertaken.

Indicator groups and individual indicators may respond differently to human disturbance in the catchment, and may respond differently in different catchments. For example, in the Liao pilot study, no single biotic indicator responded consistently to the disturbance gradients in all river regions. For example, no algal indicators were responsive in the highlands, and no fish indicators were responsive in the midlands. This highlights the need for a suite of indicators, and for indicators to be selected that are suitable to the particular location.

Ecosystem health indicators should:

- quantify threats and assets (drivers, stressors and responses)
- provide easily interpretable outputs
- respond predictably to damage caused by humans
- respond at appropriate time scales
- be cost effective to measure
- relate to management goals
- be scientifically defensible.

Focus on a consistent approach to collecting data

After basic data on a river system has been collected, it is possible to calculate and assess the suitability of a large number of indicators. Initially, it is most important to focus on getting the right data – the best indicator can be determined at a later date. The data collection process should be supported by a rigorous quality assurance program that can be implemented consistently by all involved. The quality of any river health analysis and subsequent recommendations depends on the quality of the data. Consistent processes need to be established for sampling, data entry, data storage and use, and laboratory analyses. Reliable field and analytical data is best achieved by implementing a QA/QC plan.

Establishing reference values for different indicators

Establishing appropriate reference values against which indicator values can be assessed is a major challenge. The pilot studies set reference values based on a combination of existing Chinese guidelines, international standards, and by extrapolating the data collected during the study. While these were adequate for the purposes of the pilot studies, these values have significant limitations and would need to be refined to ensure their suitability to Chinese conditions. For example, while indicators based on the tolerance of different species of macroinvertebrates are, in principle, readily transferrable to China, the actual tolerance values may not be. Chinese-specific tolerance values are needed, based on local taxonomy and tolerance patterns of individual taxa. Establishing a central repository of ecological data collected as part of river health assessments would provide an excellent basis for developing reference values that are appropriate for Chinese rivers.

Reference values will also vary significantly between different rivers and regions within China. The abundance and composition of different biota in healthy rivers is likely to vary, for example, between upland and lowland streams, between tributaries and trunk streams, and between the wet and dry catchments. Water quality parameters can also show significant natural variation. These threshold and target values need to be set for the appropriate local conditions, but using a standard approach.

In implementing a national river health assessment program, a balance should be struck between avoiding prescriptive guidelines on indicators and reference values, while ensuring that the methods for data collection and analysis are sufficiently similar to allow results from different rivers and regions to be compared.

In the first instance, guidelines can be developed through a combination of (i) drawing on international or national standards and experience (e.g. water quality guidelines; biotic indices) (ii) historical data (iii) the statistical distribution of scores within the relevant basin. Using a combination approach, national standards for each indicator group for different river types can develop over time. This process would benefit from a national river classification system.

Managing differences in river type through river classification

It is important to recognise the differences in river types when developing a monitoring program:

- Different types of rivers will not look and behave the same, even when they are healthy. There is considerable natural variation in water chemistry and biota in rivers from different climatic and bio-geographic settings and even within single river basins from headwaters to the sea.
- The types of indicators that might be appropriate in one type of river may not be appropriate for another.
- The methods used to sample in one river type may not be possible or relevant in another.
- Even where the same indicator can be used in different river types, the thresholds or targets are likely to differ.

Because of these natural differences, it is often inappropriate to directly compare indicator threshold and target values from very different types of rivers. This challenge may be addressed by a river classification based on landscape and climatic features that are known to influence water quality and biota (such as rainfall, runoff, temperature, geology, topography and other landscape features), but are not directly influenced by human activity. This classification could be done at a relatively coarse scale initially and refined as the need arises.

A river classification would allow rivers and catchments that are similar to be grouped together. Indicators and threshold values for indices can then be determined for each class of river, identifying for each river type:

- standards and thresholds for water quality and biological indicators
- aspects of the flow regime that are environmentally significant.

It may be possible to adapt existing classification systems.

Adopting a common reporting framework

A common objective for national governments in developing (national) river health assessment programs is to be able to compare the relative health of different rivers. This allows the government to identify priorities for funding of restorative action and to assess the relative success of conservation and restoration activities. This can result in pressure to adopt common indicators and reference values across a country. However, natural regional variations in climate, geology and other environmental factors and differences in the range and intensity of land use make the development of a national river health assessment program in any country a major challenge.

Future river health monitoring should be guided by a framework to ensure that a consistent approach can be adopted across different basins. This will allow results to be easily compared and yet still meet the specific needs of each region. It is important, therefore, that such a framework is not overly prescriptive and allows flexibility for local adaptation. For example:

- Guidelines may identify a consistent set of indicator groups (e.g. fish, macro-invertebrates, water quality, vegetation), but have flexibility in the choice of specific indices within each group. The specific indicators can then be selected to suit the local circumstances. Each of the indicators can be scaled (e.g. 0–1) to reflect the range of threshold and target values. Provided results are scaled in the same way – so a 'good' score or a 'poor' score is equivalent – it doesn't necessarily matter if different indicators or indicator groups were used in calculating river health scores: the scores can still be compared with one another.

- An important consideration at the outset is to adopt a consistent national approach to data collection and analysis, including methods for site selection, sampling of indicator groups and data storage and quality control. Provided the necessary raw data is collected in a consistent manner, specific indicators to be reported can be finalised at a later date, and if necessary, additional indicators can be explored.

Communication of results

Effectively communicating the results of river health assessments is an important outcome of the process. Internationally, there are a number of examples of the use of 'report cards' as a way of presenting the results of detailed technical analyses of river conditions that is readily comprehensible by a wide range of (non-technical) stakeholders. Report cards can be a valuable tool for disseminating the results of a river health study, as well as a way for generating political and grassroots support for actions to improve river health.

In preparing a report card, careful consideration needs to be given to the objective of the report, including who the intended audience is and the particular message it is trying to convey:

- different audiences (e.g. scientists, policy makers, general public) may require different levels of detail
- different audiences may require different strategies for communication and engagement.

The way information is presented in a report card must make sense to the audience. It is primarily a communication tool and needs to be underpinned by a more technical report about the data.

To prepare a report card, the detailed and complex information from a suite of indicators needs to be simplified:

- The threshold values for 'pass' and 'fail' marks will need to be rescaled (e.g. from 0 to 1) so that all indicators are comparable.
- Individual indices can be combined within an indicator group, for example indices relating to fish can be combined as a single 'fish' score. Several water quality parameters can be grouped as an overall water quality indicator.
- When combining indices, it may be necessary to take the minimum score for any one parameter, rather than the average. For example, if the water is toxic for one metal, then it should be regarded as toxic, even if all other water quality indices are below the trigger value, which is the same philosophy used in assigning a water quality grade in the existing Chinese system.
- When combining indicator groups into a single report card score, different weightings may be given to some indicator groups depending on the goals of the program.

As well as reporting on the condition of individual sites at a particular point in time, it may be valuable to report on the proportion of sites in a region that are passing or failing, or to report on trends over time. The condition trend – that is, whether it is improving, declining, or stable – can be more important, than reporting on absolute values when assessing which rivers are at risk, or whether interventions are being successful.

The integrity of a report card depends on the scientific process that underpins the report card: a glossy brochure is not a substitute for a sound scientific study. It is critical that any limitations of the scientific assessment are not lost as part of the simplification of the report card.

Implementing the monitoring program to inform management

River health monitoring and reporting need to be developed in the context of an adaptive process that:

- is clearly linked to identified values and objectives
- is informed by rigorous science
- guides management actions
- is responsive to changing perceptions and values of stakeholders.

It is very important to consider the resources (budget and staff) needed to develop and implement the monitoring program. In general the costs are tied to:

- the number of field sample sites
- how the field sites are selected
- how frequently you sample in the field
- the number of indicators you intend to measure
- how frequently you intend to report.

Regardless of cost considerations, there are some aspects of the program that must be considered:

- sufficient sites and measurements to achieve the statistical power required to report on the objectives
- a set of well written guidelines about how to carry out all aspects of the monitoring work
- a quality control and quality assurance program to make sure the data is being properly collected and analysed
- good training programs to certify the skills of the field and laboratory workers
- ongoing technical review of the program to continually refine and improve the methods
- a well resourced communications team whose job is to effectively communicate the results to management and the wider community, and to document the management response to the monitoring program
- a data management system for archiving all of the data in a standard way, and for making the data and reports readily accessible.

Programs will not be effective unless there is strong collaboration and communication between policy makers and the scientists involved in undertaking the program. Programs will also fail if they are not sufficiently well planned and resourced.

2.9 Draft national guidelines for river health assessment

The project has developed a draft national guideline for river health assessment in China. The draft guideline recognises the availability of data, the challenge of limited resources, and the need for an approach that can be used in a wide variety of different river systems.

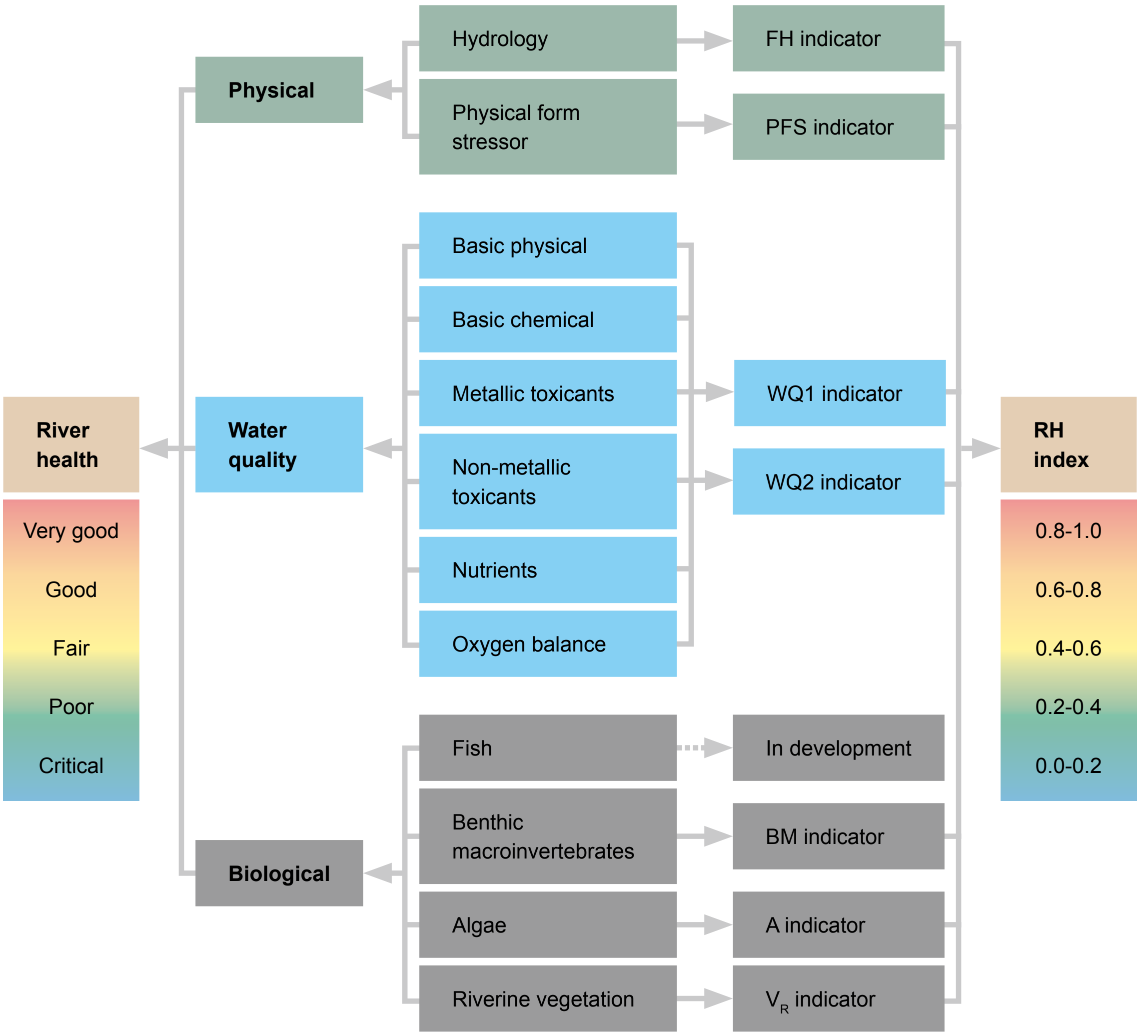
The framework for the draft guideline is shown in Figure 24. The framework includes a number of core physical, biological, and water quality indicators. These indicators are:

- Hydrology: the Index of Flow Deviation.
- Physical form stressor: an index that incorporates indices related to longitudinal and lateral connectivity, sediment risk, bed disturbance, bank stabilisation, and interruptions to flow.
- Riparian vegetation: the three sub-indicators recommended relate to the width and the longitudinal continuity of the riparian vegetation buffer, and cover abundance of trees, shrubs and ground cover of the riparian vegetation buffer.
- Water quality: six sub-indicator groups are included (see Figure 24). The Chinese national water quality standards are used as the benchmark, using a method similar to that described for the Yellow River pilot in section 2.4.
- Benthic macroinvertebrates: EPT richness ratio and SIGNAL 2.
- Algae: Four algae sub-indicators are proposed. Two of these are diatom composition indicators, the Biological Diatom Index (Indice Biologique Diatomées, or IBD), and Specific Pollution Sensitivity Index (Indice de Polluosensibilité Spécifique, or IPS). The other two sub-indicators are chlorophyll a abundance indicators: benthic (periphyton) chlorophyll a, Chl-aPer, and suspended (phytoplankton) chlorophyll a, Chl-aPhy.

- Fish: fish are included in the guideline for data collection purposes. However, given the lack of historic data and the challenge in setting meaningful reference values, it is recommended that fish are not included in any river health reporting in the first instance. As more data is collected, it will be possible to identify suitable indicators and reference values.

Indicators are scored on a range from 0 to 1, based on defined reference values, with different values set for different river types. The draft guidelines[11] include principles for selecting indicators, defining reference values, selecting sampling sites, determining frequency and timing of sampling, and data measurement, storage, and reporting.

Figure 24: Proposed framework for river health assessment.



11 Technical Regulation for Assessment of River Health (draft), March 2012. Available from www.watercentre.org

Chapter 3. Environmental flows

3.1 Importance of environmental flows

The water regime is the most important factor that shapes freshwater ecosystems.[12] By dramatically changing the hydrology and hydraulics of rivers, flow regulation has altered the ecology and geomorphology of river channels and riparian zones, as well as downstream ecosystems including coastal and estuarine areas. There is now widespread recognition of the importance of allocating water and managing rivers in a way that recognises the flow requirements of freshwater ecosystems.

Flow regimes – that is, the overall pattern of flow, including the magnitude, timing, frequency and duration of flows, seasonality and variability across years – are important to river health for a number of reasons. Flow is a major determinant of the physical habitat in rivers. Flows maintain longitudinal (i.e. upstream–downstream) and lateral (i.e. river–floodplain) connectivity. Changes to flow regimes facilitate the spread of unwanted pest species. Many aquatic species have evolved life history strategies in response to their natural flow regimes.[13]

A naturally variable flow regime is integral to diverse healthy rivers, riverine wetlands, floodplains, groundwater systems and estuaries: without it these ecosystems, and the services and functions that they provide, would not exist. Riparian and in-stream development, flow regulation, and the abstraction of water, all of which can affect the flow regime, can have significant consequences for both rivers and the people, communities and businesses that depend on them. Flow alteration can:

- reduce the quality of freshwater, including its suitability for human use
- affect the movement of sediment and alter channel morphology, which can increase the risk of flooding and reduce navigability
- increase saline intrusion, which can affect water supplies and riparian land
- reduce groundwater recharge and the availability of groundwater as a water supply
- impact on riverine and riparian goods, species and ecosystems used by humans, including vegetation, fish, and other aquatic fauna
- reduce cultural and spiritual values and the suitability of rivers for recreational activities.

The development and utilisation of water resources does provide significant benefits to society, particularly through increased and more reliable water supplies, the production of hydropower, and reduced risk of flooding. These benefits must be balanced with the impacts on the natural environment and the various goods and services that rivers provide to society. This balancing act is now a fundamental element of water resources planning, allocation, and management. It affects decisions on where water infrastructure will be built, how it will be operated, and generally how much water can be abstracted for consumptive purposes. These decisions need to be made with an understanding and consideration of the impacts on environmentally important flows.

12 Puckridge, JT, Sheldon, F, Walker, KF & Boulton, AJ 1998, 'Flow variability and the ecology of large rivers', *Marine and Freshwater Research*, vol. 49, pp. 55–72.

13 Bunn, SE and Arthington, AH 2002, 'Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity', *Environmental Management* vol. 30 pp. 492–507.

3.2 Objectives and scope of assessing environmental flow requirements

The objectives of this component of the project were to:

- develop and demonstrate a method for assessing environmental flow conditions appropriate to the pilot rivers, and more broadly to Chinese conditions
- assess and make recommendations on the flow requirements to sustain key ecological assets in the lower Yellow and Li Rivers
- assess the suitability of the methodology for application in China
- review international approaches of incorporating environmental flows into water allocation and management systems
- propose a national environmental flows framework suitable for China.

The objectives were addressed through two separate, but related, tasks:

(i) The development of a national environmental flows framework. A review was undertaken of policy measures and mechanisms for assessing and implementing environmental flows, including the use of regionalisation and classification to support environmental flows. This review was used as the basis for a national environmental flows framework.

(ii) An assessment of the environmental flow requirements for the lower Yellow and Li Rivers was undertaken. The pilot studies were used to test a generic environmental flows assessment methodology, to make recommendations on flow requirements for the river, and to provide a basis for aspects of the river health assessment work.

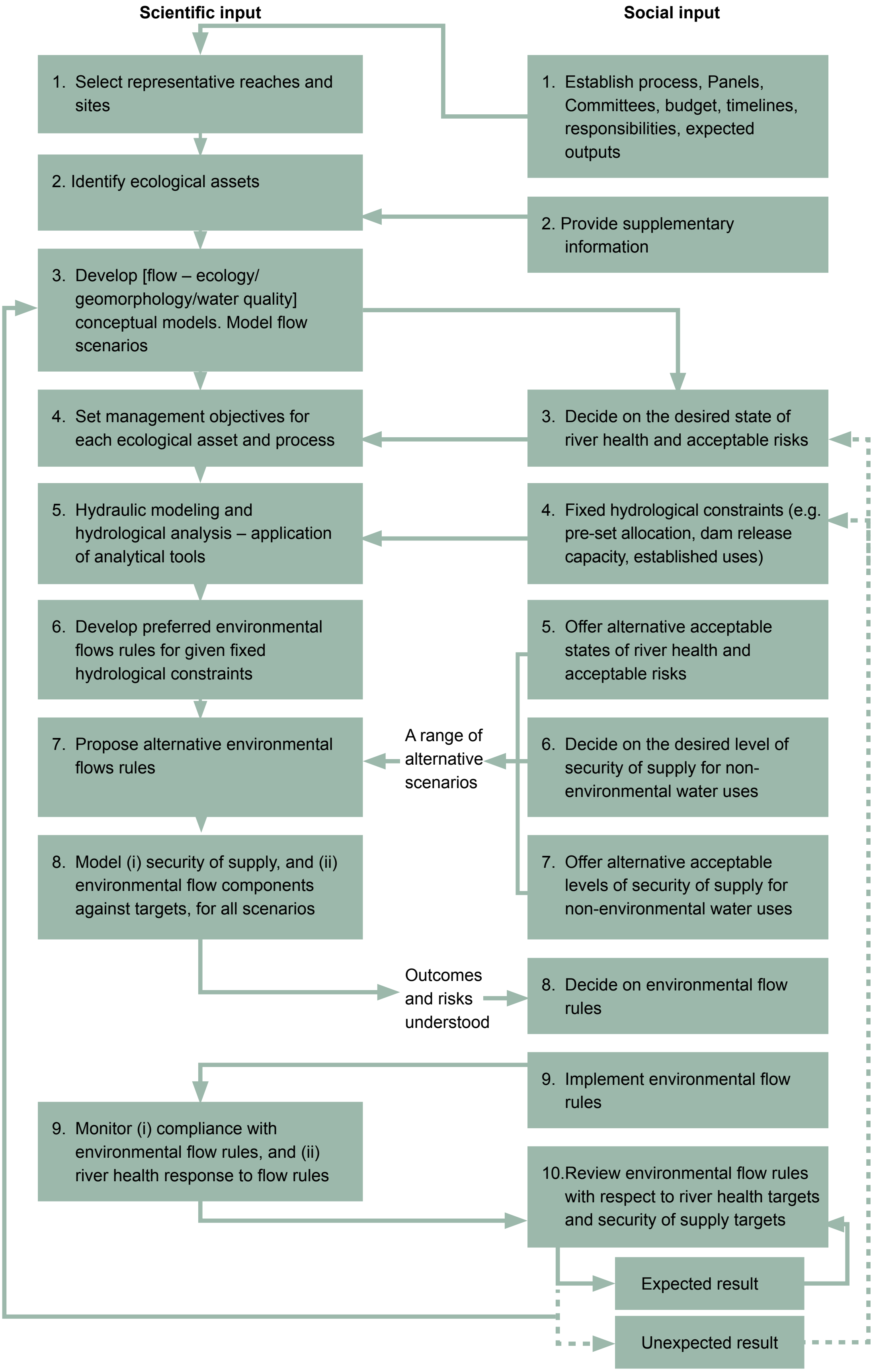
3.3 Environmental flows Yellow River pilot study

Not all rivers require the same flow pattern to maintain their functions and ecosystems. What is important in one river, or to one ecological community, may be very different in another. Different assets and processes can require very different flows, in terms of size, frequency, timing and duration. The most important elements of the riverine environment and system need to be determined. The elements that the government or the community want to restore, protect and use also need to be identified, along with the required flows.

The pilot study followed a generic environmental flow assessment framework developed as part of the project and shown in Figure 25. The approach was loosely based around the FLOWS methodology, used in Victoria, Australia. The FLOWS methodology is also a derivative of the Building Block Methodology that was first developed in South Africa.[14]

14 Tharme, RE and King, JM 1998, Development of the Building Block *Methodology for instream flow assessments and supporting research on the effects of different magnitude flows on riverine ecosystems*, WRC Report No. 576/1/98 Freshwater Research Unit, University of Capetown, Capetown.

Figure 25: Generic environmental flows assessment method.



This framework can accommodate any form of environmental flow assessment, any analytical tools, any size river, any existing constraints (regulated or unregulated, pre-existing allocation), any existing or proposed river uses, and any balance of scientific or stakeholder input to the process. A detailed site-specific assessment would involve all of the steps in the framework. Where time or resources are limited, or where a comprehensive assessment is not necessary, only some of the steps need to be undertaken. While a result can still be obtained by omitting certain steps, it will weaken confidence in achieving the expected outcomes and increase the risk of unexpected and unacceptable outcomes.

The key steps in this framework, as applied to the Yellow and Li Rivers, are discussed in the following sections. The process described below focuses on the Yellow River pilot, which involved the most detailed assessment.

Identify assets and reaches

Defined as specific locations, the project identified eight key ecological assets in the lower Yellow River:

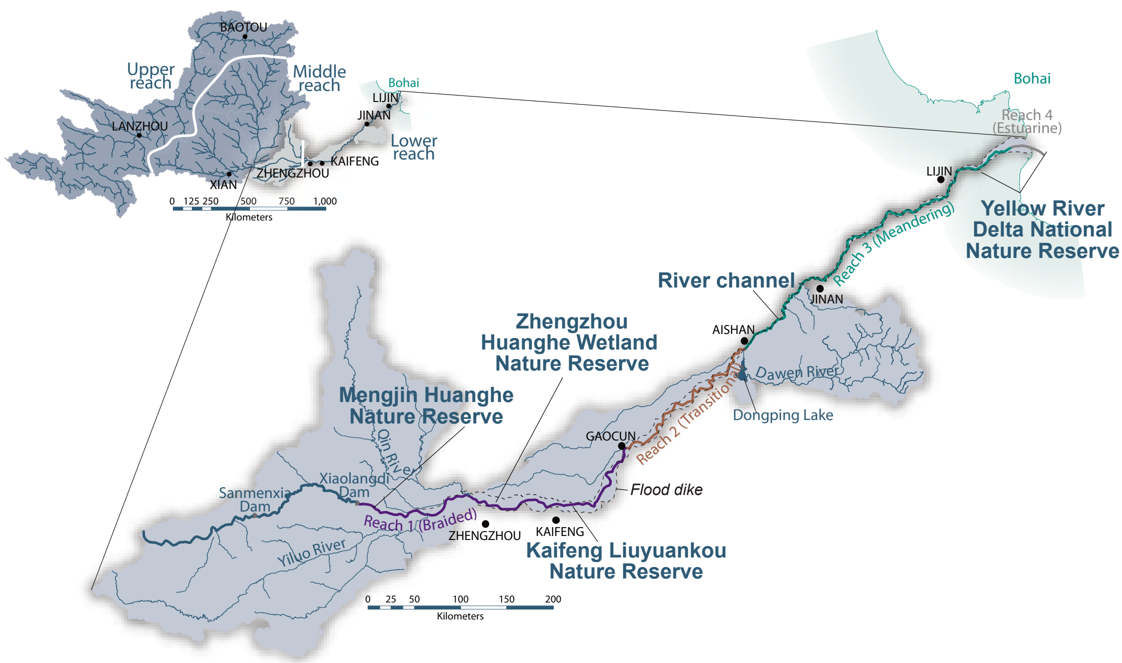
1. Triver channel from Xiaolangdi dam to the Bohai
2. Mengjin Huanghe Nature Reserve
3. Zhengzhou Huanghe Wetland Nature Reserve
4. Yubei Huanghe Gudao Nature Reserve
5. Kaifeng Liuyuankou Nature Reserve
6. Dongping Hu
7. Yellow River Delta Nature Reserve
8. intertidal zone around the Yellow River Estuary and the Bohai

The Yellow River also has ecological assets in the form of important species and communities of waterbirds, fish, macroinvertebrates and plants, plus the ecosystem functions that support them. These assets are all represented in the eight listed locations.

The lower Yellow River was divided into four reaches, based on physical and ecological characteristics. An existing reach division was modified to suit the project's objectives. Information about flow-ecology and flow-geomorphology relationships was collected specific to these reaches. This information was collated through literature and data reviews, aided by a scientific panel consisting of Australian and Chinese experts and by field visits to the assets.

Figure 26 shows the lower Yellow River's four reaches and its key ecological assets.

Figure 26: Lower Yellow River basin, showing the four reaches and key ecological assets.



For the Li River, a meeting with officials from the Pearl River Water Resources Commission and the project team identified the following broad asset groups:

1. rare fish species
2. riparian wetlands
3. tourism
4. navigation
5. drinking water
6. hydropower
7. irrigation water.

Setting flow objectives

The existing management objectives of the YRCC (see section 2.4) were used as guiding principles in setting specific environmental flow management objectives.

This process aimed at identifying the flow needs of the key ecological assets. These assets are wetlands, the delta, and the river channel. Individual assets within these asset classes were also identified, such as species, communities and physical and chemical processes. The following groupings of assets were then considered for the purposes of identifying specific flow objectives:

- geomorphology
- hydrology
- water quality
- water birds
- fish
- macroinvertebrates
- plants.

The scientific panel established flow objectives related to each of these groups, based on a conceptual understanding of the flow-ecology, flow-geomorphology, and flow-water quality relationships. This work was primarily undertaken at a three-day workshop.

Tables specifying flow objectives for each asset group and each of the four river reaches were created. These flow objectives were expressed as flow magnitudes, with an associated frequency, timing, duration and rate of rise and fall. Finally, the objectives were merged to create a consolidated set of objectives that would jointly meet the requirements of the range of different assets. A sub-set of the flow objectives is shown in Table 8.

Table 8: Sub-set of the environmental flow objectives for the lower Yellow River.[15]

Obj. met	Objectives description	Flow component	Hydrologic criteria	Mean annual frequency/ duration	Inter-annual frequency	Timing	Reach
F1; M1	Prevent habitat loss through drying of shallow areas	Cease to flow	Q ≥ YRCC warning standards of low flow emergency to prevent cease to flow	Continuous	100% of the time	All year	All reaches
B1; B2; B3	Expose Carex and mudflats; shallow water over submerged aquatics	Low flow	Exposure of "soft beach"	Continuous	≥ 75% of the time	Nov - Jun	Reach 1
F2	Maintain shallow habitats with moderate-high velocity for shallow water dwelling species and spawners during low flow periods	Low flow	Provide areas with with D = 0.5 – 1.5 m and V ≤ 2.0 m/s	Continuous	≥ 75% of the time	All year	Reaches 1 - 3
WQ1, WQ2, WQ3, WQ4	Dilute contaminants to Grade III standard	Low flow and high flow	≥ 320 m3/s (Reach 1); ≥ 234 m3/s (Reach 2); ≥ 146 m3/s (Reach 3); ≥ 60 m3/s (Reach 4)	≥ 90% of time	≥ 75% of the time	All year	All reaches
V3; V4	Maintain Tamarix/ Salix shrubland and woodland	Low flow and high flow	Maintain shallow groundwater at 0.5 (Jul-Sep) and 1.5 – 3.0 m (all year) from surface of "second beach"	Variable	-	All year	Reach 1
M2; M5; F3; F4; F11; F16	Maintain reasonable area of habitat for most of the time for longitudinal connectivity, survival of large-bodied fish, maintenance of primary productivity in the estuary; and maintenance of DO levels in deep pools	Low flow and high flow	≥ 80% of wetted area at pre-Sanmenxia median baseflow for each month	Continuous	≥ 75% of the time	Each month	All reaches

An equivalent process was completed for the Li River, establishing flow objectives related to geomorphology, water quality, fish, riparian vegetation, and tourism (transport).

Hydraulic modelling

Hydraulic modelling was undertaken to convert objectives specified as hydraulic criteria (e.g. flows required to inundate a certain percentage of the riverbed, or of a wetland) into hydrologic objectives. For the Yellow River pilot, two models were built and applied:

- an HEC-RAS 1-D hydraulic model, for the entire lower Yellow River, based on 365 transects measured as part of routine channel monitoring surveys
- a River2D 2-D model, for three key sites in the pilot area, based on hydrographic surveys undertaken as part of the project work.

A summary of the discharges required to achieve particular hydraulic criteria, as well as information on the model used, is shown in Table 9.

15 'Obj. met' refers to which of the broader objectives is met by the particular flow. F1, F2, etc. refer to objectives related to fish, M to macroinvertebrates, WQ to water quality, B to birds. Q = velocity and D = depth.

Table 9: Discharges required to achieve required hydraulic objectives, based on models and previous studies.

Obj.	Component	Model used	Reach	Desirable discharge range (m3/s) (gauge for compliance)
A	Cease to flow	Previously known	Reach 1	≥ 150 (HYK)
			Reach 2	≥ 120 (GC) and ≥ 80 (SK)
			Reach 3	≥ 100 (LK)
			Reach 4	≥ 30 (LJ)
B	Low flow	1-D	Reach 1	< 500 (XLD and HYK)
C	Low flow	2-D	Reach 1	Any discharge (peak at low Q) (XLD)
			Reach 1	Any discharge (high at 700 – 2,000; peak at 1,000) (HYK)
			Reach 2	Model not available (assume same as Reach 3) (SK)
			Reach 3	Low at 1,200 – 2,400; high at 100 – 900; peak at 500) (LK))
D	Low flow and high flow	Previously known	Reach 1	≥ 300 (XLD) and ≥ 320 (HKY)
			Reach 2	≥ 234 (GC) and ≥ 146 (SK)
			Reach 3	≥ 146 (LK)
			Reach 4	≥ 60 (LJ)
E	Low flow	1-D	Reach 1	300 – 1,000 (XLD and HYK)
	High flow	1-D	Reach 1	≥ 1600 (XLD and HYK)
F	Low flow and high flow	1-D	All	See Table 4 for monthly minimum flows

In the Li River, the flow volumes required to achieve hydraulic objectives were determined using a 1-D hydraulic model, built using 99 cross-sections.

Recommended environmental flow regime

Following the hydraulic analysis, the environmental flow objectives were specified in terms of hydrologic requirements.

In the Yellow River, two environmental flow options were proposed: one would present a low risk to achieving good river health, and the other a medium risk.

The flow options were constrained by certain operational requirements that were considered unalterable, at least in the short term. The main constraint was the need to keep flow within the confines of the main channel, due to the risk to human life and socio-economic values that floods would present. This in turn limited the maximum allowable flow.

The low-risk flow regime achieves all of the flow objectives, except for certain flows linked to vegetation within reach 1, where it was not considered realistic to achieve flows of sufficient magnitude to meet the objective. The medium-risk flow regime was formulated by taking the low-risk regime and reducing the base flows and, in the case of reach 1, removing the low-flow pulse. Eliminating the low-flow pulse would detrimentally impact the health of riverine wetlands. Table 10 shows the low-risk environmental flow regime for reach 1. Similar tables of recommendations were prepared for the other three reaches, as well as for the alternate, medium-risk, flow regime.

Table 10: Low-risk environmental flow regime for reach 1 of the lower Yellow River. Huayuankou is the compliance point.

Objectives met	Flow component	Hydrologic criteria	Mean annual frequency/ duration	Inter-annual frequency	Timing
F1; M1	Cease to flow	No cease to flow	Continuous	100% of the time	All year
B1; B2; B3, F2; WQ1, WQ2, WQ3, WQ4; V3; M2; M5; F3; F4; F11; F16	Low flow	Dec ≥ 307 Jan ≥ 280 Feb ≥ 321 Mar ≥ 377 Apr ≥ 463 May ≥ 430	Continuous	≥ 75% of the time	Dec - May
F6; F7; F9; V1; B5; M3; M4; F14	High flow	Jun ≥ 434 Jul ≥ 783 Aug ≥ 1,137 Sep ≥ 1,124 Oct ≥ 866 Nov ≥ 543	Continuous	≥ 75% of the time	Jun - Nov
V3; V4; F10	Low flow pulse	≥ 2,000	≥ 1 per year / 1 – 30 days; rates of rise and fall within natural range	≥4 in 5 years	Nov - May
G1, G2, G3, G4, WQ6; B6; B7; B8; F12; F13; F5; F10	Bankfull	3,000 – 4,000	≥ 1 per year / ~10 – 30 days duration; rates of rise and fall within natural range	≥4 in 5 years	Jun – Sep

The recommended flow regime for the Li River is shown in Figure 30. This flow regime includes three different flow values: the median estimate represents the flow volume that meets the objective at 50 per cent of the cross sections, while the upper and lower bounds represent the flow required to achieve the objective at just one, or all of the cross sections respectively.

Table 11: Summary of flow recommendations for Li River.

						Flow volume required (m^3/sec)		
Flow objective ID*	**Flow component**	**Mean annual frequency/ duration**	**Inter-annual frequency**	**Timing**	**Rate of rise/ fall**	**Med**	**Up**	**Low**
T1, T2, F1, F2, F3, V1, V2, WQ 1, WQ2	Low flow	Continuous	Every year	Sep–Feb	-	60	60	60
G1	Low flow pulse	1 per year	Every year	Mar–Apr	See report	100	750	20
F5, F7	High flow	Continuous	Every year	Apr–Sep	-	60	400	20
F6	High flow	Continuous	Every year	May–July	-	100	100	100
F4, F6, V3, G2, G3	High flow pulse	1–2 days followed by	Every year	Apr–Jun	See Figure 10	2000	2000	1000
		10–20 days		Apr–Jun	>1.2m in 12 hours	200	200	200

Environmental flows, water allocation and scheduling

The final stage of the environmental flow assessment process was to determine how the preferred flow regime could be implemented, taking other demands for water into account. Typically, this assessment should be done as part of the water allocation planning process.

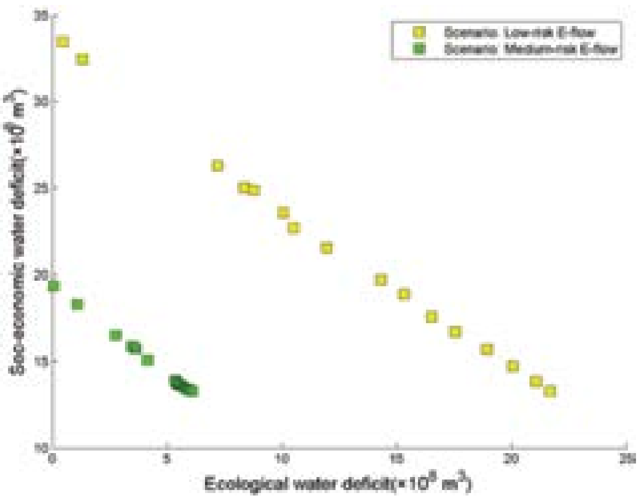
Environmental flows, water allocation and scheduling were only considered for the Yellow River pilot. A modelling exercise estimated future water demands and identified an optimal approach to scheduling (primarily releasing water at different times for different purposes) that could maximise the benefits to the environment, the economy, and people. The modelling considered the entirety of the Yellow River (i.e. not just the lower reaches).

The process involved:

- A macroeconomic input-output model was developed. This model formed the basis of a macroeconomic water resources model, to calculate the domestic, economic and external ecological water demand of the Yellow River under different development scenarios and for different reference years. These results were then compared to the Yellow River Water Resources Master Plan.
- A water allocation model for the lower reach of the Yellow River was built to determine the optimal ecological water use. The model included the main reservoirs, river reaches and the region that used the most water. For the lower Yellow River, the model used the environmental flow recommendations developed as part of the project. For the middle and upper reaches, the model used recommendations developed through previous studies.
- Using the outputs from the water allocation model under different water demand and water infrastructure scenarios and by studying the impacts of water conservancy projects on ecological water scheduling, the project identified a recommended ecological water use scheduling plan. The water use scheduling plan balances the different competing interests in the basin. This analysis considered the extent to which there were shortfalls in the water required for agricultural purposes, domestic and industrial purposes, and ecological purposes. The impacts of water transfer projects, including the South-to-North Water Transfer Project, were also considered.

The analysis shows that, under current conditions, there will be major challenges in meeting both socio-economic and ecological water requirements. Water transfer projects, such as the South-to-North Water Transfer Project, will increase the water available in the basin, but this will be offset by growth in demand.

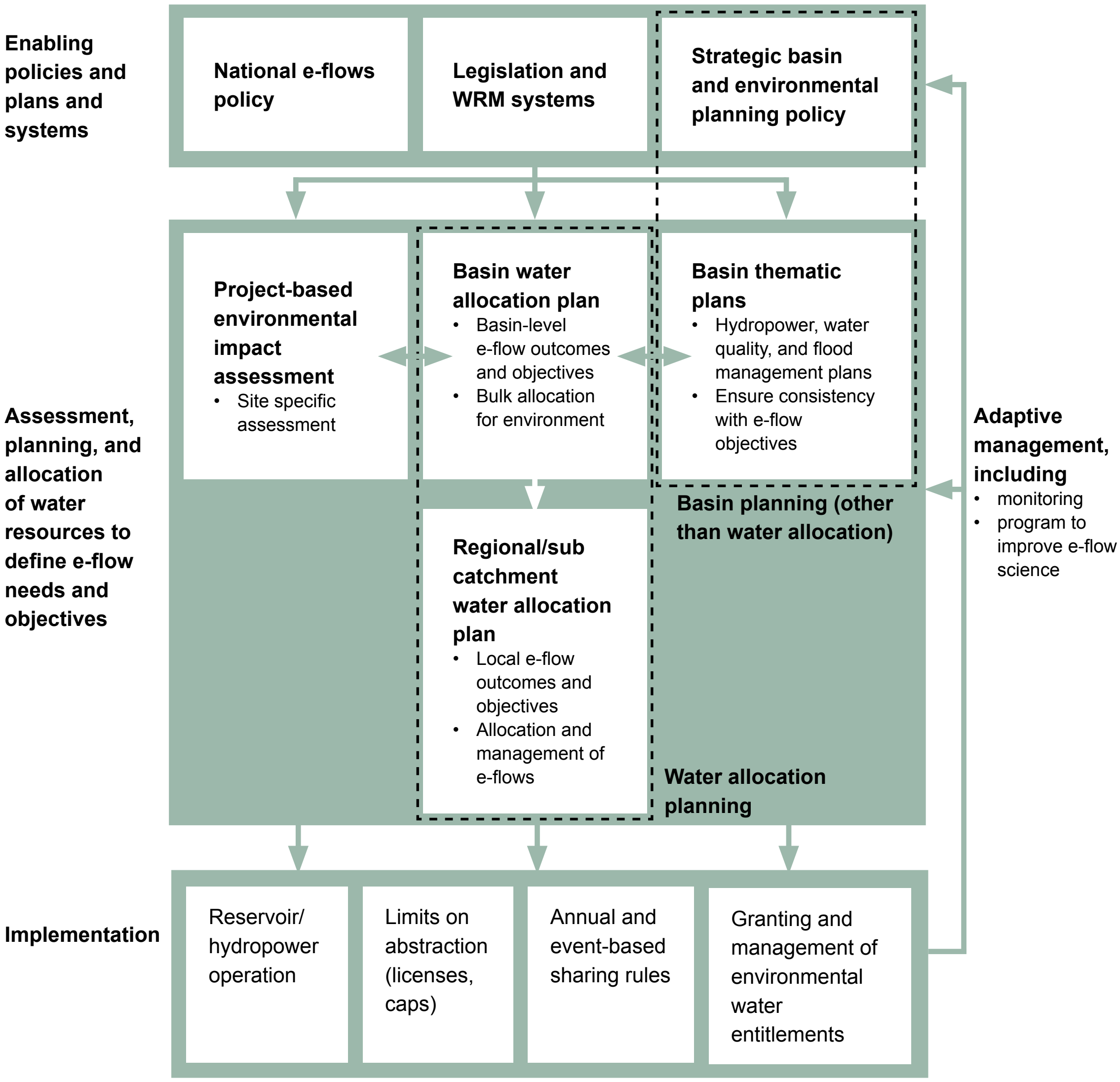
Figure 31: Water deficits in the base year for the two different environmental flow scenarios.



3.4 National environmental flows framework

The project proposes a national environmental flows framework shown in Figure 32. The framework identifies the elements of a national system for determining environmental flow requirements and for incorporating those within allocation and management arrangements.

Figure 32: National environmental flows framework.



The framework has been developed taking China's existing legal and institutional arrangements and requirements into account. However, the national environmental flows framework is generic and intended to be suited to any situation. It is flexible and should be adapted to meet the local context, including the particular priorities and the capacity and resources of local agencies, as well as the high-level governance regime. The framework identifies three key elements: the enabling environment, the assessment and planning process, and implementation requirements.

Enabling policies, plans and systems

Appropriate policies and legislation are critical to promote and support the establishment of environmental flows. Agreement on the objectives of, and approach to, achieving environmental flows is essential. In addition, implementing environmental flows depends on having an effective water resources management and regulatory system; in particular, there must be effective controls over water abstractions and the operation of water infrastructure for environmental flows to be delivered.

Where possible, environmental flows assessment and implementation should be supported by basin-level planning to identify strategic environmental goals and to prioritise competing objectives for water and river resources. This is more likely to be an issue in larger or more complex basins, where there are likely to be many competing uses and users.

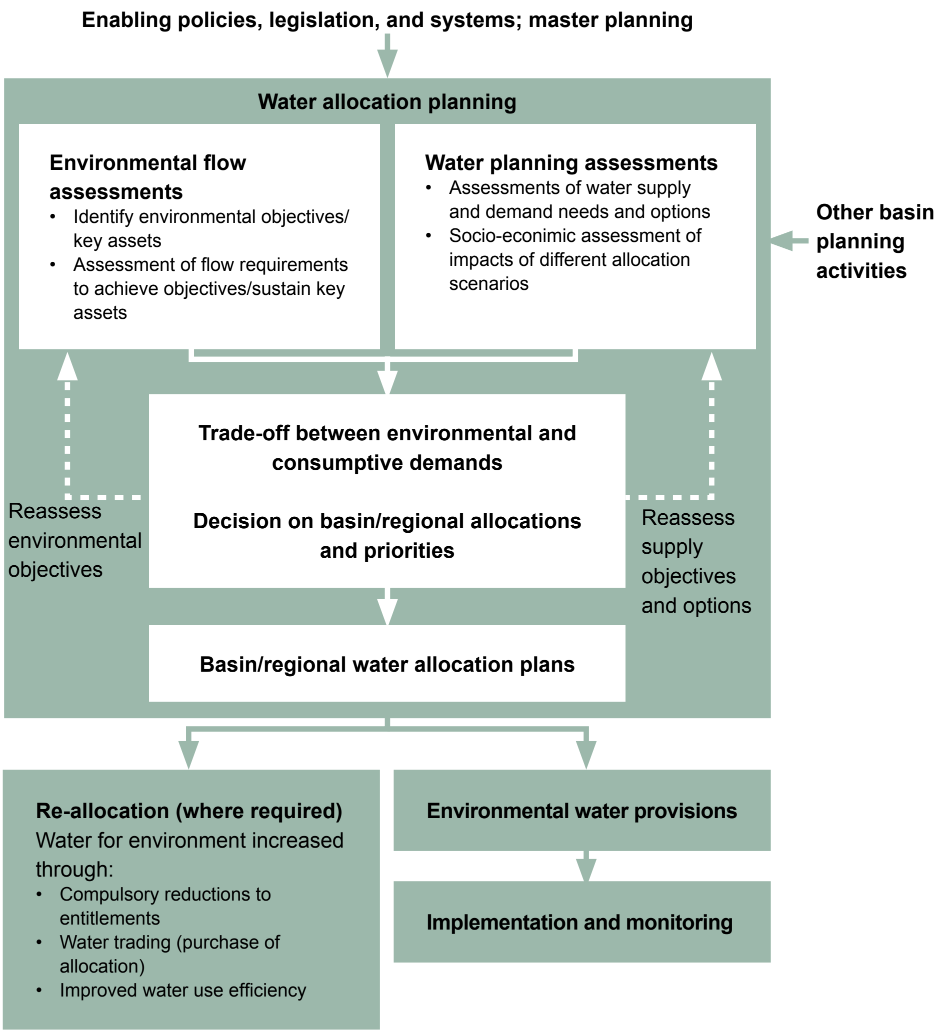
Environmental flows assessment and water allocation planning

An assessment of environmental water requirements should form the foundation of the water allocation planning process. Figure 33 expands on the water allocation planning aspects of the framework. The assessment process should identify:

- the environmental objectives for the river basin, such as important environmental assets or processes to be sustained
- the flow regime required to meet those objectives (e.g. to sustain important assets in the desired condition).

The framework used in as part of the Yellow River environmental flows study (Figure 25) provides a method suitable for undertaking the environmental flow assessment 'box' shown in Figure 33.

Figure 33: Water allocation planning and environmental flows framework.



The water allocation process is fundamentally a socio-economic process. While an environmental flow assessment may identify a preferred flow regime, the water allocation process should reconcile these requirements with the needs of other water users. This may involve adjusting or trading off environmental objectives against other uses.

The ultimate purpose of the environmental flow assessment process is to make informed allocation decisions. The process should ensure that where water is allocated to the environment, that this water is used in the most effective way. Similarly, where decisions are made not to provide water for certain environmental purposes, these decisions are undertaken with an understanding of the risk of environmental damage and the likelihood of loss of environmental goods and services.

Allocation planning can occur at multiple levels via nested plans. This may be required because of the legal or political situation, or simply because of issues of scale. Basin and regional and subcatchment plans need to be aligned in their approach to allocating water, setting objectives, and defining environmental flow requirements.

The assessment and implementation of environmental flow requirements can also be undertaken at a local scale, outside of a planning process. Project-based environmental flow assessments focus on the local impacts of a new (or existing) project, such as a reservoir or hydropower station. This type of assessment can provide an opportunity to:

- develop and establish environmental flow rules where none currently exist
- establish more detailed environmental flow rules, to complement those already established by an over-arching allocation or management plan, which may involve testing or refining assumptions made as part of an earlier environmental flows assessment.

Implementation of environmental flows

There is a range of regulatory mechanisms that can be used to provide and protect the desired environmental flow regime. These options are not mutually exclusive, and it may be appropriate to adopt a suite of measures.

Achieving environmental flow objectives can require regulation of the total volume of water that may be abstracted, the timing, rate and antecedent conditions that govern water abstractions or releases, and the location and design of in-stream infrastructure. Options for specifying and implementing environmental flows include: caps and limits on abstractions; managing hydro-power operation, minimum flows and special flow release; pre-conditions to abstraction and event-based management rules; and granting environmental water entitlements.

Caps and limits on abstractions: A water allocation plan may reserve a volume or percentage of the available water for environmental purposes, with water entitlements (e.g. licences) granted to other water users, consistent with this reserve volume. If estimates of the available water supplies are correct, and water users do not exceed their entitlements, the reserved water should remain in the river system for environmental purposes. A cap on abstractions can be a critical first step in protecting flows for the environment; experience shows it can be extremely difficult to recover water for the environment. This approach can be effective in reserving water for the environment, but it also involves some risk. If an allocation plan overestimates the amount of available water, or if the available amount reduces (e.g. through climate change) the environment may suffer from any shortfall. During periods of drought, the environment may suffer disproportionately from the reduction in available water.

Managing hydro-power operation, minimum flows and special flow releases: A water allocation plan, or infrastructure operation rules, may define a minimum volume of water that must be flowing in the river at certain locations and at certain times. This approach can be used to regulate the actions of infrastructure operators, including hydropower production, and can specify environmental flow requirements in terms of:

- minimum daily releases (e.g. to maintain base flows)
- requirements to pass-through certain events (e.g. environmentally important pulses)
- maximum rates of rise and fall (to minimise ecological harm caused by rapid changes in flow rate or depth)
- requirements not to release water at certain times (e.g. in rivers that are periodically dry under natural conditions).

This type of approach can be particularly relevant if total water abstraction is low (that is, mean annual flows remain high relative to natural levels), but significant hydropower development means there is a potential for major changes to the seasonality and variability of the flow pattern.

Pre-conditions to abstraction and event-based management rules: A water allocation plan or an abstraction permit may prescribe flow conditions that must be met before water is abstracted, or it may limit the amount of water that can be abstracted. This approach can allow for environmental water requirements to be given priority by limiting water abstraction by other users until environmental needs have been met. Similarly, a water allocation plan or water abstraction licence may reduce the amount of water users may take during defined, environmentally important events.

Rules may require a reservoir operator to pass these flows, or part of these flows, through its infrastructure. This approach can require real-time decisions about whether or not a flow event meets particular criteria, and whether environmental needs are to be prioritised over other users' needs.

Granting environmental water entitlements: Environmental flows can be provided and managed by granting water entitlements for environmental purposes, equivalent to the entitlements (or licences) granted to consumptive users. In this instance, the entitlement is grated to an entity that is charged with using the water in a way that achieves certain environmental objectives. In Australia, entitlements have been granted through the creation of statutory 'environmental water holders'.

The environmental water entitlements are treated the same way as consumptive water entitlements, and are allocated a volume of water seasonally or annually in accordance with the local water sharing rules. The water is then available to the environmental water holder to be used, as appropriate, to achieve the maximum environmental benefit.

An advantage of this approach is that it can provide greater protection to environmental interests during dry periods, as well as allowing for greater flexibility in the way environmental water is used, with the environmental water holder able to make decisions throughout the year based on the seasonal conditions and the amount of water available to it.

3.5 Key considerations in implementing environmental flows

Environmental flows are critical to maintaining a river's ecological health. Providing environmental flows requires:

- determining the flows that need to be protected or provided to maintain the riverine environment in a desired condition
- management and regulatory systems to ensure that those flows are achieved.

Significant advances have been made in recent years in establishing methods for meeting these requirements, in China and elsewhere internationally. High-level policies and legislation dealing with environmental flows are now in place, or under consideration, in most major countries around the world. At the same time, methods for assessing environmental flow requirements have progressed significantly over the past ten years and there is now broad consensus on the underlying science of environmental flows.

Despite these developments, progress in implementation remains poor across the world. In most cases, environmental flows implementation has stalled at the policy level, with relatively few instances of environmental flows being incorporated within allocation rules and operating arrangements. Where water has been allocated for the environment, it has often been done in a simplistic manner, with little understanding of the underlying environmental needs and at levels below what is required to achieve a healthy ecosystem. In many instances where environmental flows have been adopted or are being considered in China, they are at levels below what is required to achieve a healthy ecosystem.

The project work identified the following key considerations in implementing environmental flows:

Identify and define environmental goals and priorities: Environmental flow assessment and implementation need to be undertaken with a clear understanding of the broad environmental objectives for the basin: what ecological assets and services are of importance, and the condition in which they are to be maintained. This, in turn, relies on recognising of the value of the goods and services that rivers provide for human communities.

Environmental flow objectives should be determined based on the requirements to maintain or restore those assets and services. Establishing arbitrary minimum daily or annual flow requirements without first identifying key assets and services, and the flows required to maintain them, can be both an inefficient approach to providing environmental water and also greatly increases the risk of unacceptable ecological harm and the loss of river function.

Tailor the approach to suit the situation: Flow requirements to maintain ecological health can vary significantly between different river types, and based on the particular assets and services of importance. The magnitude, timing, and frequency of flows that are required to maintain one river system will not necessarily be suitable to another. Likewise the management approach may vary depending on whether a system is regulated or unregulated, the types of threats the system is facing, and the types of flows to be protected or provided.

The method used for assessing environmental flow requirements should be determined based on the local context. In highly developed basins, those with a large number of competing interests, or where there are high-value environmental assets, it may be appropriate to undertake a detailed environmental flow study and a sophisticated approach to water allocation and flow management may be required. In other situations, a relatively simple desktop assessment may be adequate for the purposes of establishing a preliminary cap on abstractions.

Recognise the limitations of basic hydrological assessment methods: Hydrology-based methods, such as the Tenant method, are popular because of their simplicity. However, such methods are unlikely to provide a scientific basis for assessing environmental flow needs in most Chinese rivers. Assessment methods need to be applied that can account for the different hydrology, hydraulics, and ecology in Chinese rivers.

Cap abstractions as soon as possible: It is much easier to implement requirements on new users than to enact changes to existing use. Experience demonstrates that it is better to adopt a precautionary approach and to introduce a cap on abstractions now – even where environmental water requirements may be unclear – and limit the risk of a difficult future water re-allocation process. At the same time, where water is already over-allocated, a cap must be seen as only the starting point, with subsequent efforts made to reduce water usage.

Recognise the links between environmental protection, water allocation, and development objectives: Environmental water needs should provide the foundation on which basin allocation planning is be built. The water allocation planning process should though provide the mechanism for identifying and reconciling competing demands on the basins resources, and be done in a way that recognises the role of water in development and aligns with overarching developmental and environmental objectives. Understanding linkages between water allocation and development becomes increasingly important in water-stressed basins.

Adopt an approach that protects environmental interests during periods of scarcity: Past practice suggests that environmental flow regimes are particularly susceptible to curtailment during periods of water shortage. This is often the period when flows are of greatest importance to the environment. However, water sharing arrangements can mean that the environment suffers disproportionately at these times compared with other users. Management rules should ensure an equitable and appropriate approach to sharing water during these times.

Maintain capacity to adjust to changing circumstances: Changes in climate, the economic and social situation, government priorities, and scientific understanding of a river basin can all require adjustments to water allocations and the environmental flow regime. Management systems should retain sufficient flexibility to be able to adjust to new circumstances.

Make informed decisions about environmental flows and water allocations: The establishment of environmental flows should be based, to the greatest extent possible, on deliberate, informed decisions. The process of allocating and managing water resources should involve:

- identifying the river's assets, values and functions to be protected or restored
- reserving water to meet the flow needs of those assets, values and functions, including provision for a complete flow regime – not just minimum flows – based on an understanding of the links between flow and ecology.

Importantly, where a decision is made to not provide water for the environment (or for certain environmental assets or services) this should be done deliberately, rather than by default, and in a transparent way. Such decisions should be made with an understanding of their potential impacts on the river's ecosystems and the goods and services the river would otherwise provide.

It is recommended that the issues be fundamental considerations as China develops a national system for identifying and implementing environmental flows.