# The Mekong River Commission

THE COUNCIL STUDY

STUDY ON THE SUSTAINABLE MANAGEMENT AND DEVELOPMENT OF THE MEKONG RIVER, INCLUDING IMPACTS OF MAINSTREAM HYDROPOWER PROJECTS

## COMPARISON BETWEEN ENVIRONMENTAL FLOW ASSESSMENT TOOLS

**November 2014**

Acknowledgements

This paper was prepared for the Mekong River Commission Secretariat, using literature and models kindly provided by many colleagues and their organisations involved in integrated flow management.  The following contributors are gratefully acknowledged (listed in alphabetical order): Dr Jeroen Aerts, Dr Chris Barlow, Dr Ashley Halls, Dr Eduard Interwies, Dr Ian Jowett, Dr Jackie King, Dr Ralph Lasage, Dr Marcel Marchand, Dr Matthew McCartney, Dr Brian McIntosh, Dr Pedro Monteiro, Professor James Morrissey, Dr Jaroslav Mysiak, The Nature Conservancy, Dr Ian Payne, Dr David Rankin, Professor Ezio Todini, Dr Bill Young.

*Note:*

*At the request of the MRC, this paper was prepared by Cate Brown, who is a developer of DRIFT, one of the methods reviewed.  She made a concerted effort to be objective regarding review of all of the methods presented here.*

# Contents

1 Introduction ........ 3
1.1 The Council Study ........ 3
1.2 Purpose of this overview ........ 4
2 Types of Environmental Flow assessment methods ........ 5
3 Selection and comparison criteria ........ 7
3.1 Criteria used for selecting a DSSs for inclusion in the overview ........ 7
3.2 Criteria used for the comparison of DSSs ........ 9
4 Comparison of the DSSs ........ 11
5 Advantages and vulnerabilities of DRIFT in the context of the Council Study ........ 16
5.1 Conclusion ........ 17
6 Literature ........ 18

# List of Tables

Table 2-1 Features of prescriptive and interactive methodologies (Brown and King 2003) ........ 6
Table 3-1 DSSs compared (in alphabetical order) ........ 8
Table 3-2 The criteria used for the comparison of DSSs ........ 9
Table 4-1 Comparison of DSSs ........ 11
Table 5-1 Advantages of DRIFT in the context of the Council Study ........ 16
Table 5-2 Vulnerabilities of DRIFT in the context of the Council Study ........ 17

# 1 Introduction

## *1.1 The Council Study*

Since its establishment in 1995, the Mekong River Commission (MRC) has been involved in the collection of data and the development of models, both conceptual and mathematical, aimed at improving and demonstrating the understanding of the functioning of the Lower Mekong River (LMR) ecosystem, and the links between the people and the river. There is now a wealth of knowledge on this river system as well as valuable resources such as mathematical models:

- Hydrological models (SWAT and IQQM) for the whole of the LMR
- Hydraulic, sediment and water quality models for the delta and parts of the mainstream
- Hydrodynamic models (MIKE 11; ISIS) for the Tonle Sap Great Lake
- Data on flooding patterns, and inundation depths and duration
- Life-history and distributional data on the fish and other biotic communities
- Data on the fisheries that are supported by the river
- Data on sediment transport through the system.

The MRC has used these data and models to aid decision making on development and management of the LMR. Studies that have addressed this include

- World Bank Study (World Bank 2004)
- Integrated Basin Flow Management (IBFM; 2004-2006; MRCS 2006)
- Basin Development Plan (BDP; 2004-ongoing; MRC 2011a)
- Strategic Environmental Assessment (SEA: MRC 2011b).

The MRC has as yet not developed a model that uses the modelled physical and chemical predictions of change to predict changes to river resources, and the implications for people that depend on them. Apart from IBFM, which was terminated before the planned 4$^{th}$ phase, the above mentioned studies did not focus on detailed assessment of the impacts of developments on the river ecosystem or on the value of ecosystem services. This lack was identified as a data gap in the recent revision of the Basin Development Plan. Subsequently, at the 18th Council Meeting of the MRC[1], Member Countries' Prime Ministers agreed in principle to implement a study on sustainable management and development of the Mekong River including the impact of hydropower projects, which would address some of the existing data gaps.

This agreement led to "The Council Study".

The Council Study aims to address uncertainties in assessing the impact of different development opportunities in the Mekong River Basin, and to provide recommendations that will support informed development planning in the LMR. The development opportunities to be analysed may be located on the mainstream Mekong River or in any of its tributaries in the LMR, but the analysis of impacts of these on the river ecosystem and people will be limited to the mainstem Mekong and Tonle Sap Rivers, the Tonle Sap Great Lake and the Mekong Delta.

[1] Held in Bali, Indonesia, November 2011

One of the key challenges in implementing the Council Study was the identification of an environmental flow tool that could be used in conjunction with MRC's hydrological, hydraulic, sediment and water quality models to predict the possible changes to river resources, and impacts on users of these resources.

## 1.2 Purpose of this overview

In September 2013, the MRC approached Southern Waters about the possibility of using the environmental flow assessment approach DRIFT as the tool to be used for this purpose. After discussions between Dr Cate Brown of Southern Waters and the Council Study Coordinator, Mr Chaminda Rajpakse, and a meeting with MRC personnel involved in the study (5-7 November 2013), Dr Brown was contracted to provide a chapter for the Inception Report for the Council Study, dealing with the use of DRIFT to implement the Biological Resources Assessment module. This was submitted in December 2013.

In the Inception Report for the Council Study, the stated intention is to use the DRIFT method for this purpose (Council Study Inception Report, August 2014). In the light of this, at the presentation of the Inception Report at the 2nd Regional Technical Working Group Meeting in Phnom Penh on 11-12 September 2014, the Member Countries requested an analysis of the advantages and disadvantages of DRIFT in the context of other similar tools.

In accordance with this request, this identifies and compares the attributes of existing, computer-based decision support systems (DSSs) that can be used to assess the implications of the proposed developments on river ecosystems. DSSs were sourced internationally and compared using a pre-determined set of criteria. Some of the information in this report is based on an earlier similar comparison done by Dr Brown for the MRC in 2007, after IBFM3. Many of the shortcomings of methods identified in the 2007 report have since been addressed in DRIFT.

# 2 Types of Environmental Flow assessment methods

Recent years have seen a rapidly increasing demand to include environmental and subsistence considerations into decision making processes on water resource developments. The demand drove the development of a new science, Environmental Flow Assessments, which have become an increasingly important part of Integrated Water Resource Development. With no recipes to guide them, practitioners across the world started developing their own ways of assessing Environmental Flows and, by 2003, over 200 methods had evolved (Tharme 2003). Many included some form of scenario analysis and some, mainly in developing countries, incorporated information on social and economic aspects. Among the methods were ones focusing on rivers, or wetlands or estuaries.

Four relatively discrete types of methods evolved (Tharme 2003; Arthington *et al*. 2007):

- Hydrological methods, which represent a set of desktop techniques where hydrological data are analyzed to derive standard flow indices as recommended flows. Hydrological methods are typically prescriptive (see Table 2-1) and result in a recommended flow regime for ecosystem maintenance based on data extrapolated from areas where more detailed studies have been undertaken. They do not provide any detail on the responses of biophysical components of that ecosystem, e.g., geomorphology, water chemistry, vegetation or fish, to flow changes.
- Hydraulic rating methods, which use changes in hydraulic variables such as wetted perimeter or maximum depth as a surrogate for habitat factors known or assumed to be limiting to target biota.
- Habitat simulation or microhabitat modelling methods. These also make use of hydraulic habitat-discharge relationships, but provide more detailed, model-based analyses of both the quantity and suitability of in-stream physical habitat available to target biota under different discharges. Flow-related changes in physical microhabitat are modeled, and linked to seasonal information on the range of habitat conditions used by target fish or invertebrate species, commonly using habitat suitability index curves. The outputs, in the form of habitat-discharge curves for specific biota, or extended as habitat time and exceedance series, are used to negotiate environmental flows or, in some cases, e.g., MFat (Young *et al*. 2003), to predict the consequence of flow change for specific biota.
- Holistic (ecosystem) methodologies address the water requirements of several components of an ecosystem (Arthington *et al*. 1992) rather than the needs of just a few taxa. In doing so, they may incorporate techniques from one or more of the above types of methods.

Environmental flow assessment methodologies can also be divided into prescriptive and interactive methods (Table 2-1). Methods based on the prescriptive approach usually address a narrow and specific objective and result in a recommendation for a single flow value or flow regime to achieve it. Their outcomes tend not to lend themselves to negotiation, because effort is mostly directed to justifying the single value, and insufficient information is supplied on the implications of *not* meeting the recommended value to allow an informed compromise (Stalnaker *et al*. 1995). For this reason they are also not well suited to situations where the implications of flow change are explored. Interactive approaches on the other hand, focus on the relationships between changes in river flow and one or more aspects of the river. Once these relationships are established, the outcome is no longer restricted to a single interpretation of what the resulting river condition would be. Methods based on the interactive approach are thus better suited for use in scenario development and negotiations. They do tend to be more complex and have more onerous data and time requirements than do prescriptive approaches (adapted from Brown and King 2003).

**Table 2-1 Features of prescriptive and interactive methodologies (Brown and King 2003)**

| Prescriptive | Interactive |
|---|---|
| Provide a single flow regime to maintain a single objective (predicted river condition). | Provide predicted river condition linked to a range of flow regimes. |
| Motivate for the inclusion of specific flows. | Describe the consequences of flow manipulations. |
| Not conducive to exploring options. | Conducive to exploring options. |
| Suited for application where objectives for environmental flows are clear and the chance of conflict is small. | Suited for application where the eventual environmental flow is likely to emerge from negotiations. |

# 3 Selection and comparison criteria

The selection criteria used in this paper explicitly exclude environmental flow methods (or frameworks) that are not interactive, not computer-based, do not have scenario analysis routines and/or cannot respond to scenarios without specialist additional input; in other words, they are not functioning as DSSs[2]. Most environmental flow methods are processes or frameworks providing, for instance, a list of activities to be followed, with the decision as to what models or methods to use left to the user (Tharme 2003). They do not qualify for inclusion in this paper.

## *3.1 Criteria used for selecting a DSSs for inclusion in the overview*

DSSs for inclusion here were sourced from literature on environmental flow assessments and integrated flow management; submission of DSSs for consideration in response to an advertisement posted in 2007 to the EFlows Network managed by IUCN (16 responses were received, and seven DSSs were offered for consideration); several web searches using a variety of key phrases and words; and previous reviews of DSSs (e.g., ETV 1997; Giupponi *et al*. 2007; NatureServe 2004; King 2012). Where relevant, authors/developers were contacted directly for documentation or to provide clarification on a DSS.

The time allocated for the overview meant that it is unlikely that the DSSs presented here are a complete list. However, it is hoped that they represent a reasonable example of the array of available tools.

Only DSSs that focused on some aspect of environmental flow assessment were considered and, in order to be selected, had to meet all of the following criteria:

1 be computer-based
2 address at least one kind of riverine ecosystem, i.e., river, wetland, floodplain or estuary (groundwater was not included as a criterion)
3 address at least one biophysical component of that ecosystem, e.g., overall condition, geomorphology, water chemistry, vegetation or fish, and its response to flow changes
4 be able to provide predictions of biophysical change in response to scenarios of change in flow
5 provide extensive and clear documentation .

Adding a criterion that a DSS should consider social and economic responses to flow change as well as biophysical responses) would have eliminated too many DSSs, so this was not included

Each of the methods chosen for assessment does explicitly address one or more aspects of the relationship between flow and the biophysical aspects of a river system. Because all of them are still evolving, some aspects of them may have been missed.

[2] This includes the Ecological Limits of Hydrologic Alteration (ELOHA; www.conservationgateway.org/ConservationPractices/Freshwater/EnvironmentalFlows/MethodsandTools/ELOHA/Pages/ecological-limits-hydrolo.asp), which is a framework for environmental flow assessment – not a DSS.

**Table 3-1 DSSs compared (in alphabetical order)**

| # | Name of DSS | Countries/region where applies | Main references |
|---|---|---|---|
| 1 | BAYFISH | LWR Mekong | Baran *et al*. (2003) |
| 2 | BCG-DSS[3] | USA | Auble et al. (2008) |
| 3 | LaTrobe River BN | Australia | Hart et al. (2008) |
| 4 | Catchment to Coast (C2C) | Mozambique | Monteiro *et al*. (2006) |
| 5 | DEMIOS | South Africa | Turpie et al. (2008) |
| 6 | Desktop Model | South Africa – also many other regions as an uncalibrated version | Hughes and Hannart (2003) |
| 7 | Downstream Response to Imposed Flow Transformations (DRIFT) | Angola, Botswana, Lesotho, LWR Mekong, Mozambique, Namibia, Pakistan, Peru, South Africa, Sudan, Tanzania, Zambia, Zimbabwe. | King *et al*. (2003); Brown et al. (2013) |
| 8 | Dynamic Pool Model for Floodplain-River Fisheries (DPMFF) | Bangladesh | Halls *et al.* (2000) |
| 9 | ECOlab | Australia, Denmark, India, Singapore, Sweden, USA, currently in use in the Mekong Delta Study | DHI (2009) |
| 10 | Ecosystems Functions Model (HEC-EFM) | USA | US Army Corps of Engineers (2013) |
| 11 | EcoWin2000 | South Africa | Ferreira et al. (2008) |
| 12 | ENFRAIN | Europe | Marchand (2003) |
| 13 | Habitat Flow Stressor Response (HFSR) | Namibia, South Africa, Zambia | Hughes and Louw (2013) |
| 14 | Hydroecological integrity assessment process software (HIP-OFR) | USA | Henriksen *et al*. (2009) |
| 15 | Indicators of Hydrologic Alteration (IHA) | Widely applied across regions | Richter et al. (1996); Nature Conservancy (2005) |
| 16 | Murray Flow Assessment Tool (MFat) | Australia | Young *et al*. (2003) |
| 17 | Pressure-impact multi-criteria environmental flow analysis (PIMCEFA) | Norway | Barton and Berge (2008). |
| 18 | River Analysis Package (RAP) | Australia | Marsh (2004) |
| 19 | Water Allocation Impacts on River Attributes (WAIORA) | New Zealand | Jowett *et al*. (2003) |
| 20 | Watershed Flow Evaluation Tool (WFET) | USA (Colorado) | Colorado Water Conservation Board. (2009). |
| 21 | WFD 82 | United Kingdom | SNIFFER (2006) |

[3] Similar to the Delaware Riverine Environmental Flow Assessment DSS (Talbert et al. 2014).

## 3.2 Criteria used for the comparison of DSSs

Once a DSS was selected using the criteria discussed in Section 3.1, it was assessed and compared to the others selected in terms of another set of criteria (Table 3-2). This was designed to evaluate the extent to which it addressed the whole flow regime and the whole riverine ecosystem, and was able to make predictions of biophysical change in the response to scenarios of changed flow regimes in a target catchment.

**Table 3-2 The criteria used for the comparison of DSSs**

| **Criteria** | **Each DSS was evaluated in terms of:** |
|---|---|
| Types of ecosystem | What type of ecosystem can it be used for, e.g., rivers, lakes, wetlands. |
| Response to water-management scenarios | The extent to which it is able to provide an indication of change in a river resource, or a suite of resources, in response to changes in the flow regime, i.e., once the DSS is populated and calibrated, no additional input required from experts/specialists in order to respond to water-management scenario queries. |
| Address multiple aspects of ecosystem | The extent to which it includes predictions for different aspects of an ecosystem. |
| Provides quantitative predictions of change in river resources | Whether the indications of change in river resources are in the form of quantitative or semi-quantitative values, e.g., area, abundance, catch per unit effort. |
| Ease of calibration | How easily it is to calibrate. This is assessed on a scale of 1-5, with 1 = can be done with desktop information and 5 = requires detailed field data collections. A second aspect to this criterion was that such calibration does not require re-programming of the DSS. |
| Relationships used are transparent | The extent to which the relationships used and the pathways of information flow are transparent and can be readily understood by someone who is reasonably familiar with DSSs or modelling. |
| Includes consideration of non-flow related impacts | Whether the effects of non-flow related, or off-channel, impacts or management interventions on river resources can be considered |
| Hydrological data requirements | The time step of hydrological data that is required as input, e.g., monthly, weekly, daily or hourly. The temporal resolution of the hydrological data affects the time required to generate the data and the appropriateness of the data for determining biophysical change. For instance, monthly data are easier to generate but do not provide information on how the flow is distributed within each month, e.g., lowflows and flood events, which could affect how the ecosystem will respond. |
| Considers operating rules, e.g., peaking for hydropower | Many environmental flow studies need to assess the impact of dams and potential alternative operating rules. In particular, hydropower projects may result in daily or hourly peaking of flows. Thus, an important criterion was to what extent these types of flow regimes could be considered in the DSS. |
| Relies on expert opinion to construct relationships | Whether construction of the relationships in the DSS relies on expert opinion or some other means. |
| Allows ecological feedbacks | Whether relationships between different parts of the ecosystem can be assessed, rather than only those between flow / hydraulics and the ecosystem |
| Longitudinally linked | The extent to which the DSS is capable of taking account of upstream/downstream connectivity that could affect migration of fish, survival of life stages in other river reaches, transfer of seeds, movement of sediments and water quality considerations. |

| Criteria | Each DSS was evaluated in terms of: |
|---|---|
| Region specificity | Whether the DSS is regionally-generic and can be easily parameterised for use in any system. Often DSSs that have been programmed and calibrated for a specific project/study area can be adapted for another area but this can require more effort than for those that are designed as regionally-generic tools. |
| Single value or time-series output | Static (a prediction of change after a number of years), or dynamic (predictions of change for every year, building upon previous years) |
| Spatially explicit | Outputs link to GIS maps and charts, which aid interpretation |
| User Manual | Quality of manual not assessed – only whether a guide to application was present |
| Number of applications (estimated) | Although it is difficult to judge the number of different geographical locations where a DSS has been used, it is important to highlight that many of the DSSs were single applications, i.e. purpose built for one project. Multiple applications also ensure that a tool has been tested in, and is able to respond to, varying environmental conditions and project-specific challenges. For this reason, the number of different applications of each tool is seen as important. |

# 4 Comparison of the DSSs

Table 4-1 summaries the degree to which each DSS meets each criterion (Table 3-2).

**Table 4-1 Comparison of DSSs**

| | Types of ecosystem | Responds to water-management scenario | Address multiple aspect of ecosystem | Provides quantitative predictions | Ease of calibration | Relationships used are transparent | Includes consideration of non-flow related impacts | Hydrological data requirements? | Consideration of operating rules, e.g., HP peaking | Relies on expert opinion | Ecological feedbacks | Longitudinally linked | Region specificity | Single value or time-series output? | Spatially explicit | User Manual | Number of applications |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BAYFISH | Lake | Y | N | Y | 1 | Y | Y | ?[4] | N | Expert opinion | N | Y? | Tonle Sap | Single | N | N | 1 |
| BCG-DSS | River | Y | Y | Y | 4 | Y | N | Daily | Y? | Equations, parameters | N | N | Black Canyon, USA. | Time-series | N | Y | ? |
| Catchment to Coast (C2C) | Marine coast | Y | Y | Y | 4 | Y | Y | ? | N | Site-specific established relationships | Y | Y? | Maputo Bay, Mozambique | Time-series | Y | Y | 1 |
| DEMIOS | Estuaries | Y | Y | Y | 4 | Y? | N | not fixed | N | Expert opinion | Y | N | Kleinemonde South Africa | Time-series | N | Y | 1 |
| Desktop Model | Rivers | Y | N | N | 1 | N | N | Monthly | N | Region specific established relationships | N | N | South Africa, uncalibrated applications elsewhere | Single | N | Y | >90 |
| DRIFT | Rivers, lakes, floodplains, swamps | Y | Y | Y | 3 | Y | Y | Not fixed | Y | Expert opinion and local knowledge | Y | Y | Generic | Time-series | N | Y | >40 |
| Dynamic Pool Model (DPMFF) | Floodplains | Y | N | Y | 4 | Y | Y | Weekly | N | Site-specific established relationships | N | N | Bangladesh | Time-series | N | Y | 1 |

[4] Use of the question mark in table: when used alone ? it means the information is not known at this time; when it is use together with a response (e.g., Y?) it means that the answer given is an assumption.

| | Types of ecosystem | Responds to water-management scenario | Address multiple aspect of ecosystem | Provides quantitative predictions | Ease of calibration | Relationships used are transparent | Includes consideration of non-flow related impacts | Hydrological data requirements? | Consideration of operating rules, e.g., HP peaking | Relies on expert opinion | Ecological feedbacks | Longitudinally linked | Region specificity | Single value or time-series output? | Spatially explicit | User Manual | Number of applications |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ECO-LAB | Rivers, lakes, wetlands, marine | Y | Y | Y? | 4 | ? | Y | Daily | Y | Site-specific established relationships | Y | Y? | Generic | Time-series | Y? | Y | ? |
| EcoWin2000 | Marine Bay | Y | Y | Y | 4 | N | Y | ? | N | ? | ? | ? | Generic | Time-series | Y? | N? | 1 |
| ENFRAIM | River/ Floodplain | Y | N | Y | ? | ? | Y | ? | N | Biotope distribution maps | ? | Y | Generic | Single | Y | Y | ? |
| HEC-EFM | Rivers | Y | Y | Y | 4 | ? | N | Daily | N | Expert opinion | N | Y? | Generic | Time-series | Y? | Y | ? |
| HFSR | Rivers | Y | Y | N | 4 | N | N | Monthly | N | Expert opinion | N | N | Generic | Single | N | N | >20 |
| HIP-OFR | Rivers | Y | N | N | 4 | Y | N | Daily | N | Region specific established relationships | N | N? | Generic | Single | N? | Y | ? |
| IHA | Rivers | N | N | N | 2 | Y | N | Daily | N | Region specific established relationships | N | N | Generic | Single | ? | Y | >50 |
| LaTrobe River BN | River | Y | Y | N | 4 | Y | Y | ? | N | Expert opinion | N | N | La Trobe River, Australia | Single | N | N | 1 |
| MFat | Rivers | Y | Y | N | 4 | Y | Y | Daily | N | Expert opinion - testing of suitability curves | N | Y? | Murray River, Australia | Time-series | Y | Y | <10 |
| PIMCEFA | Rivers | Y | Y | Y | 3 | Y | N | ? | N | Expert opinion | ? | N | Generic | Single | N | Y | ? |
| RAP | Rivers | Y | Y | Y | 3 | Y | N | Daily | N? | Expert opinion / Equations | Y? | N | Generic | Time-series | N | Y | ? |
| WAIORA | Rivers | Y | N | Y | 2 | N | Y | N | N | WQ and habitat | N | N | New Zealand Rivers | Single | N | Y | <10 |

| | Types of ecosystem | Responds to water-management scenario | Address multiple aspect of ecosystem | Provides quantitative predictions | Ease of calibration | Relationships used are transparent | Includes consideration of non-flow related impacts | Hydrological data requirements? | Consideration of operating rules, e.g., HP peaking | Relies on expert opinion | Ecological feedbacks | Longitudinally linked | Region specificity | Single value or time-series output? | Spatially explicit | User Manual | Number of applications |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WFET | Rivers | Y | N | Y | 4 | N | Y | Daily | N | Region specific relationships | N | Y | Generic | Single? | Y | N? | <10 |

The main objective of Environmental Flow DSSs is to describe the relationship between the resources and the flow regime of a river system and to predict how the resources will change with flow change.

Of the DSSs in Table 4-1:

- All use a similar concept for the delivery of predictions of biological change in response to changes in flow. This is, through developing relationships between the biota, key aspects supporting them ( e.g. habitat, water quality and food) and major aspects of the flow regime.
- Most rely to a large extent on expert opinion for calibration. This is probably because they all need to integrate disparate sets of data. The exceptions are DSSs that have been specifically developed for a focus area for which empirical data are available to describe the relationships to flow, e.g., C2C.
- Two (ECOlab and WIAORA) focus mainly on water quality. WIAORA also includes some consideration of 'physical habitat for aquatic life', using RYHABSIM (Jowett 1998), and ECOlab allows quantitative, dynamic descriptions of water quality in the short- or long-term and includes nutrient dynamics, plankton, eelgrass, macroalgae and benthic fauna. ECOlab is not strictly speaking an environmental flow tool, although it has been applied in an environmental flow setting (Idaho, USA). It is currently being used in the Mekong Delta study to predict changes in water quality linked with water resource developments in the basin.
- Two (BayFish and DPMFF) address only one aspect of the river ecosystem, *viz*. fish catch. BayFish was developed specifically for the Tonle Sap River?? on the Mekong River, and DPMFF for the floodplain fisheries in Bangladesh. Both could presumably be recalibrated for other localities.
- Catchment to Coast (C2C) links the river inflow to processes in a coastal (bay) environment, and includes some linkages between the biophysical and socio-economic domains. Its focus is the near-shore and bay environments in Maputo Bay, Mozambique. Two (Desktop Model and IHA) are more prescriptive hydrological analysis tools than scenario-based holistic environmental flow DSSs. Neither can be used to predict change in specific river resources, as they focus on overall ecosystem condition.
- None of the models provide absolute quantitative predictions of change:
    - Two (BayFish and La Trobe BN) use Bayesian networks, and deliver probabilities of certain conditions occurring.
    - DRIFT translates predictions of the severity of impact into percentage change in resources, but stresses that these are NOT exact and that the trends and relative differences between scenarios should be the focal point;
    - Similarly, RAP and MFat stop short of making predictions on quantitative changes in river resources.
- Very few of the DSSs incorporate upstream and downstream effects, which are referred to here as longitudinal links (Table 3-2). For instance, the abundance of fish species in a particular zone would depend not only on the prevailing conditions in that zone but also on whether they could safely migrate to their spawning grounds, lay eggs and survive the life stages that take place in other river zones. This sort of longitudinal linking is not well-represented in the DSSs listed in Table 4-1, and the feedback loops required for

this sort of biological integration are, as far as we are aware, only included in DRIFT, albeit in a fairly rudimentary fashion. It is particularly important that longitudinal links are incorporated into the DSS used in the Council Study because of the migratory nature of the fish communities in the Mekong River.

- ENFRAIM (Marchand 2003) proposes an 'ecotope' approach to environmental flow assessments. Ecotope suitability rules are defined to link ecotopes to species groups of ecological or economic importance. Changes in the hydrodynamic situation are then reflected as changes in the ecotope distribution and consequent biological changes, e.g., fish abundance. A similar approach was used for the Okavango Delta (King et al. 2014).
- EcoLab, DEMIOS, DRIFT, HEC-EFM, MFat and RAP consider the implications of flow change for a wide array of riverine resources. Of these:DEMIOS has only been set up and used in one estuarine system, but could presumably be extended to other systems.
  - EcoLab and MFat can output across spatial scales ranging from a single site, through river zones, and up to the entire river system, whereas DRIFT has site-/reach-specific evaluations that can have up- and down-stream linkages and can be aggregated to the system level. HEC-EFM, EcoLab and Catchment to Coast (C2C) have the most spatially graphic outputs, and the former two are most closely linked to hydrodynamic models (HEC-RAS and Mike 11/21, respectively). However, both are geographically-specific, and with the same level of input similarly graphical displays could be generated for many of the other methods/models.

In summary, all DSSs have some good attributes and some weaknesses. The choice of which to use in a project could usefully be based on the requirements of the client, the number and variety of applications of the methods (which could indicate robustness of the methods), and the time and other resources available.

# 5 Advantages and vulnerabilities of DRIFT in the context of the Council Study

A summary of the advantages and vulnerabilities of DRIFT in the context of the Council Study is provided in Table 5-1 and Table 5-2, respectively. Many of these strengths and weaknesses are presented relative to other available environmental flow DSSs, as presented in the overview.

**Table 5-1 Advantages of DRIFT in the context of the Council Study**

| No. | Explanation |
|---|---|
| 1 | Has been widely applied, tested and improved over 20 years of application |
| 2 | Has been recognised as a good practice methodology by the World Bank, International Finance Corporation, Asian Development Bank, IUCN, WWF, Okavango Basin Authority, the South African, Pakistani and Tanzanian governments, and the Permanent Court of Arbitration in The Hague |
| 3 | Well documented in the peer-reviewed international scientific literature |
| 4 | Based on relationships that are transparent, clearly and simply explained, and referenced |
| 5 | Is a holistic assessment that can be used in the different types of ecosystems in the LMR: the mainstem Mekong , the Tonle Sap Lake and the Delta |
| 6 | Addresses volume and timing of all parts of the flow regime (or inundation regime in lakes and wetlands), including within-day fluctuations associated with hydropower peaking |
| 7 | Provides neutral (not pro-development or anti-development) information on ecological consequences associated with development scenarios |
| 8 | Can include composite indicators representing social-ecological-economic interactions |
| 9 | Integrates well with the outputs of hydrological and hydraulic models |
| 10 | Facilitates the combination of disparate data sets and local knowledge to provide an integrated picture of the effects that water resource development and/or management interventions can have on the ecosystems |
| 11 | Can import and use non-hydrological/hydraulic time-series information such as, for the LWR Mekong, the outputs of existing sediment (ISIS), erosion and water quality (IQQM) models. |
| 12 | Can be calibrated against time-series monitoring data. |
| 13 | Has a user manual for the software and guidelines for all steps of the process |
| 14 | Promotes capacity building within countries by employing national specialists to create the response curves and interpret the scenarios, and/or assist with managing the DRIFT process |
| 15 | Provides semi-quantitative (as a percentage change from baseline) predictions of change for all parts of the ecosystem, which can link within the DSS to the social assessment, or be incorporated into other external social and economic assessments |
| 16 | Is supported by a dedicated experienced process team, with over 20 years of experience in completing similar assessments in equally challenging environments. |
| 17 | Once the basin hydrological and other models are set up and the DRIFT DSS is populated with the response curves, calibrated and producing results, it is a relatively short and easy task to analyse any number of other scenarios of interest. |
| 18 | A fully functioning DSS is handed to the client, which can be used to explore further scenarios. |

**Table 5-2 Vulnerabilities of DRIFT in the context of the Council Study**

| No. | Explanation |
|---|---|
| 1 | Reliant on good quality, accurate hydrological and hydraulic data as the starting point for the whole assessment. |
| 2 | Scenario processing by the software can be slow at times (i.e. 2-4 hours), particularly in large catchments with many sites and hundreds of indicators, or with hourly flow data. |
| 3 | Uses expert opinion and local knowledge where data are sparse, in order to predict broad trends of change |
| 4 | Construction of response curves can be time consuming, particularly if there are many links |
| 5 | Poor spatial representation of results |
| 6 | Some of the outputs require post-processing in MS Excel in order to produce report-friendly tables and graphics |
| 7 | Currently entirely reliant on Southern Waters team for initial setup and population of the DSS. A short (1 day) training session, would allow someone else to import new scenarios and process the results. More experience with the approach would allow someone to assist specialists in creating and refining their response curves. Full training to independently run DRIFT takes longer (mentoring on several small or one large project) and has also been done. |

## 5.1 Conclusion

The DRIFT process and DSS have shortcomings as do all the environmental flow methods available; the same can arguably be said about models in general. The environmental flow methods are growing in sophistication as they are applied to a variety of ecosystems and development situations, and share many attributes in a generalised way. Key considerations are their:

- robustness in a variety of projects
- ability to link with incoming modelled data from physical models and provide outputs to economic and social models
- transparency
- ability to address such vexing problems as sediment and fish movements along a system.

None of the other DSSs compared in Section 4 appear to offer all of:

(a) all of the attributes listed above;
(b) a generic approach that could be applied to the Council Study, without an equivalent or considerably longer investment in setup time than is required for DRIFT, and;
(c) the specific tools required for the LMR study.

# 6 Literature

ARTHINGTON, A.H., BARAN, E., BROWN, C.A., DUGAN, P., HALLS, A.S., KING J.M., MINTE-VERA, C.V., THARME, R.E. and WELCOMME, R.L. 2007. Water requirements of floodplain rivers and fisheries: existing decision-support tools and pathways for development. Colombo, Sri Lanka: International Water Management Institute (IWMI Comprehensive Assessment Research Report 17).

ARTHINGTON, A.H.; KING, J. M.; O'KEEFFE, J.H.; BUNN, S.E.; DAY, J.A.; PUSEY, B.J.; BLUHDORN, D.R.. and THARME, R.E. 1992. Development of a holistic approach for assessing environmental flow requirements of riverine ecosystems. In: Proceedings of an International Seminar and Workshop on Water Allocation for the Environment. J. J. Pigram; B. P. Hooper (Eds). Armidale, Australia: Centre for Water Policy Research, University of New England. 282 pp.

AUBLE, G.T., WONDZELL, M. and TALBERT, C. 2009. Decision support system for evaluation of Gunnison River flow regimes with respect to resources of the Black Canyon of the Gunnison. Version 2009.6. U.S. Geological Survey Open-File Report 2009–1126, 25 p. Accessed from website: http://www.fort.usgs.gov/Products/Software/BCGDSS/ on 17 February 2010. (USGE: BCG-DSS).

BARAN, E., MAKIN, I. and BAIRD I.G. 2003. BayFish: a model of environmental factors driving fish production in the Lower Mekong Basin. Contribution to the Second International Symposium on Large Rivers for Fisheries. Phnom Penh, Cambodia, 11-14 February 2003.

BARTON, D.N. and BERGE, D. 2008. Pressure-impact multi-criteria environmental flow analysis in the Glomma River. STRIVER Technical Brief No. 6. www.striver.no. (PIMCEFA).

BEUSTER, H. and LUGOMELA, G. 2005. Pangani River Basin Flow Assessment (FA) Initiative Development and Application of a Systems Model to Inform Water Allocation Decisions. Unpublished Internal Report for IUCN and the Pangani Basin Office. 3pp.

BROWN, C.A. 2006. Flow-Assessment Predictive Tool. Mekong River Commission (MRC) IBFM Phase 3 series of reports. 46 pp.

BROWN, C.A. AND KING, J.M. 2003. Water Resources and Environment Technical Note C1. Environmental Flows: Concepts and Methods. 28 pp. In: Davis, R. and Hirji, R. (eds.). The World Bank Water Resources and Environment Technical Note Series. The World Bank, Washington, D.C.

BROWN, C.A. and JOUBERT, A. 2003. Using multicriteria analysis to develop environmental flow scenarios for rivers targeted for water resource development. Water SA Vol. 29 (No. 4).

BROWN, C., PEMBERTON, C., GREYLING, A. and KING, J. 2005. DRIFT User Manual: Volume 1: Biophysical Module for predicting overall river condition in small to medium sized rivers with predictable flow regimes. WRC Final Report, May 2005.

BROWN, T.C., DIAZ, G.E. and SVEINSSON, O.G.B. 2002. Planning water allocation in river basins. Aquarius: A system’s approach. Proceedings of 2nd Federal Interagency Hydrologic Modelling Conference, Subcommittee on Hydrology of the Advisory Committee on Water Information, July 28-August 1, 2002, Las Vegas, NV.

COLORADO WATER CONSERVATION BOARD. 2009. Watershed Flow Evaluation Tool pilot study for Roaring Fork and Fountain Creek watersheds and site-specific quantification pilot study for Roaring Fork watershed. Draft report prepared by Camp Dresser & McKee Inc, Brian

Bledsoe, Bill Miller, LeRoy Poff, John Sanderson and Thomas Wilding. Accessed from website: http://cwcb.state.co.us/IWMD/COsWaterSupplyFuture/ on 17 February 2010. (WFET).

DIAZ, G.E.; BROWN, T.C. and SVEINSSON, O.G.B. 1997 (last revision August 2000). Aquarius: A modeling system for river basin water allocation. General Technical Report RM-GTR-299. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 172 pp.

ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAMME (ETV). 1997. Criteria for selection of environmental Decision Support Software Technology Demonstration Participants. 6 pp.

FERREIRA, J.G., HAWKINS, A.J.S., MONTEIRO, P., MOORE, H., SERVICE, M., PASCOE, P.L., RAMOS, L. and Sequeira, A. 2008. Integrated assessment of ecosystem-scale carrying capacity in shellfish growing areas. *Aquaculture* 275: 138–151 (EcoWin2000

GIUPPONI, C., MYSIAK, J. and DEPIETRI, Y. 2007. Harmoni-CA Report. Decision Support Systems for water resources management: current state and guidelines for tool development. IWA Publishing, London UK. ISBN: 1234567890.

HALLS, A.S., KIRKWOOD, G.P. and PAYNE, I.A. 2001. A dynamic pool model for floodplain fisheries. J. Ecohydrology and Hydrobiology. 1(3), 323-339.

HART, B.T., SHENTON, W. and CHAN, T. 2009. Bayesian Network Models for Environmental Flow Decision-making. Final Report prepared for Land & Water Australia. 160 p. Accessed from website http://lwa.gov.au/products/pn30155 on 17 February 2010. (BN).

HENRIKSEN, J. A., HEASLEY, J., KENNEN, J.G., and NIEWSAND, S. 2006, Users' manual for the hydroecological integrity assessment process software (including the New Jersey Assessment Tools): U.S. Geological Survey, Biological Resources Discipline, Open File Report 2006-1093, 71 p.

HUGHES, D.A. and HANNART, P. 2003: A desktop model used to provide an initial estimate of the ecological instream flow requirements of rivers in South Africa. *Journal of Hydrology* 270, 167-181.

JOWETT, I. 1998. Hydraulic geometry of New Zealand rivers and its use as a preliminary methods of habitat assessment. Regulated Rivers 14:451-466.

KING, J.M., BROWN, C.A. and SABET, H. 2003. A scenario-based holistic approach to environmental flow assessments for regulated rivers. *Rivers Research and Application*s 19 (5-6). Pg 619-640.

KING, J.M. and LOUW, D. 1998. Instream flow assessments for regulated rivers in South Africa using the Building Block Methodology. Aquatic Ecosystems Health and Restoration Vol. 1. 109-124.

KOFALK, S., BOER, S., DE KOK, J-L., MATTHIES, M. and HAHN, B. 2005. A decision support system (DSS) for river-basin management in the Elbe catchment. Unpublished introduction to the ElbeDSS. 9 pp.

NATURESERV. 2004. Tools for coastal-marine ecosystem-based management: A survey and evaluation of utility, sustainability and opportunities for further development. Report for the David and Lucile Packard Foundation: September 15, 2004. 59 pp.

NIWA. 2004. WAIORA Version 2.0. National Institute for Water and Atmospheric Research, Ltd. Hamilton.

MARCHAND, M. 2003. Environmental Flow Requirements for Rivers: An integrated approach for river and coastal zone management. Final project report. Accessed from http://www.library.tudelft.nl/delftcluster/PDF-files/DC1-624-4.pdf.

MARSH, N. 2004. River Analysis Package - Users Guide. Software Version V1.0.1. © CRC for Catchment Hydrology, Australia 2004. Accessed from website http://toolkit.ewater.com.au/Tools/RAP on 17 February 2010. (RAP).

MEKONG RIVER COMMISSION (MRC). 2011a. Strategic Environmental Assessment.

MEKONG RIVER COMMISSION (MRC). 2011a. Basin Development Plan Scenario Assessments.

MCINTOSH, B., DI PIERRO, F., THIAM-KHU, S., FOX, C., SAVIC, D., SEWELL, M., TRAN, H. and OWEN, A. 2006. Taking account of water supply infrastructure in land-use planning: an integrated supply-demand approach. International Environmental Modelling and Software Society Biennial Summit, July 2006, Vermont, USA.

MONTEIRO, P. and MATTHEWS, S. 2003. Catchment2Coast: Making the link between coastal resource variability and river inputs. South African Journal or Science, 99. Pg 299-301.

O'KEEFFE, J., HUGHES, D., THARME, R.E. 2002. Linking ecological responses to altered flows, for use in environmental flow assessments: the Flow Stressor-Response method. Verh. Int. Ver. Limnol 28: 84-92.

RICHTER, B.D., BAUMGARTNER, J.V., POWELL, J. and BRAUN, D.P. 1996. A method for assessing hydrologic alteration within ecosystems. Conservation Biology, 10(4), 1163-1174.

SIEBER, J., SWARTZ, C. and HUBER-LEE, A. 2005. WEAP21 – User Guide. Stockholm Environment Institute.

SIEBÖGER, I. 2006. Researchers update software to manage SA water. Grogott's Mail: Digital Edition. Posted: June 15, 2007, 4:00 pm.

Smajgl, A. and Ward, J. 2013. The Water-Food-Energy Nexus in the Mekong Region. Assessing development strategies and assessing transboundary impacts. Springer. ISBN 978-1-4614-6120-3. 231 pp.

SNIFFER. 2006. Development of environmental standards (water resources). Stage 3: environmental standards for the Water Framework Directive. Report to the Scotland and Northern Ireland Forum for Environment Research. Centre for Ecology and Hydrology, Wallingford and University of Dundee, Dundee. http://www.sniffer.org.

STALNAKER, C., LAMB, B.L., HENRIKSEN, J., BOVEE, K. and BARTHOLOW, J. 1995. The Instream Flow Incremental Methodology: A primer for IFIM. Biological Report 29, March 1995. US Department of the Interior. National Biological Service. Washington, D.C. 46 pp.

TALBERT, C., MALONEY, K.O. HOLMQUIST-JOHNSON, C. and HANSON, L. 2014. User's manual for the Upper Delaware River Riverine Environmental Flow Decision Support System (REFDSS). Open-file Report 2014–1183. Reston, VA: U.S. Geological Survey. 23 p

THARME, R. E. 2003. A global perspective on environmental flow assessment: emerging trends in the development and application of environmental flow methodologies for rivers. River Research and Applications 19(5-6): 397-441.

TURPIE, J.K., JOUBERT, A.R., BABIKER, H., CHAUDHRY, J., CHILD, M., HEMPSON, T., HUMPHREY, G., JOSEPH, G., LA GRANGE, R., LIPSEY, M., MANN, G., OKES, N., PUTTICK J. and WISTEBAAR, T. 2008. Integrated ecological economic modelling as an estuarine management tool: a case study of the East Kleinemonde Estuary. Volume I. The economic value of the East Kleinemonde Estuary and impacts of changes in freshwater inputs. WRC Report No.1679/1/08. and Volume II: Model Construction, Evaluation and User Manual. (DEMIOS)

THE NATURE CONSERVANCY. 2005. Indicators of Hydrologic Alteration Version 7 User's Manual.
US ARMY CORPS OF ENGINEERS. 2013. HEC-EFM. www.hec.usace.army.mil/software/hec-efm/. Accessed 29 October 2014.
WADDLE, T.J. (ed.) 2001. PHABSIM for Windows: User's Manual and Exercises: Fort Collins, CO, U.S. Geological Survey, 288 p
WORLD BANK. 2004. Modelled observations on development scenarios in the Lower Mekong Basin. In: Mekong regional water resources assistance strategy. Report prepared for the World Bank. Mekong River Commission, Vientiane Lao PDR.
YATES, D., SIEBER, J., PURKEY, D. and HUBER-LEE, A. 2005. WEAP21: A Demand-, Priority-, and Preference-Driven Water Planning Model: Part 1, Model Characteristics. Water International, 30 (2005), pp. 487-500.
YOUNG, W.J., SCOTT, A.C., CUDDY, S.M. and RENNIE, B.A. 2003. Murray Flow Assessment Tool – a technical description. Client Report, 2003. CSIRO Land and Water, Canberra