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Sharing Water

Mobilizing Science for Healthy Ecosystems

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UNESCO Jakarta
Regional Science Bureau for Asia and the Pacific

United Nations
Educational, Scientific and
Cultural Organization

Mobilizing Science for Healthy Ecosystems is a report prepared by Dr. Mohamed Roseli bin Zainal Abidin, for the 8th World Water Forum 2018, under the coordination of UNESCO Office Jakarta as Asia and the Pacific Regional Process ecosystems theme leader.

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“Fresh water resources are an essential component of the Earth’s hydrosphere and an indispensable part of all terrestrial ecosystems”

Agenda 21, Chapter 18

“Water, it is the basic element of human activity and man draws water mainly from the rivers for his activities. The results of the diverse human activities taking place in the river basin are reflected in the river. Therefore we consider that the river basin must be taken as the basic unit in solving water problem”

Message to The Hague: From the Sector Consultation “Water in Rivers”, November 1999, Tokyo

“Of all the social and natural crises we humans face, the water crisis is the one that lies at the heart of our survival and that of our planet Earth”

Koïchiro Matsuura (Water Year 2003) Former UNESCO Director-General

“Our indispensable water resources have proven themselves to be greatly resilient, but they are increasingly vulnerable and threatened. Our growing population’s need for water for food, raw materials and energy is increasingly competing with nature’s own demands for water to sustain already imperiled ecosystems and the services on which we depend. Day after day, we pour millions of tons of untreated sewage and industrial and agricultural wastes into the world’s water systems. Clean water has become scarce and will become even scarcer with the onset of climate change. And the poor continue to suffer first and most from pollution, water shortages and the lack of adequate sanitation”

Ban Ki-moon
Former UN Secretary General

“We recognize that people are at the centre of sustainable development and, in this regard, we strive for a world that is just, equitable and inclusive, and we commit to work together to promote sustained and inclusive economic growth, social development and environmental protection and thereby to benefit all”

Rio+20 Outcome Document, the Future We Want

Mobilizing Science for Healthy Ecosystems
Executive Summary

"Water is the core of sustainable development and critical for socio-economic development"

Mobilizing Science for Healthy Ecosystems is critical to help meet the challenges for sustainable development, as it lays the foundations for new approaches and technologies to identify, clarify and tackle global challenges for the future. Science can thus significantly contribute to sustainable development, but requires to that end a broad understanding of science as such.

Without healthy ecosystems, our ability to ensure water security for the world's growing population is significantly compromised. While the degradation of ecosystems and the water- related ecosystem services they provide has yet to be halted, the importance of the relationship between ecosystem health and water security is increasingly recognized in the global water discourse. Investment in water security is a long-term pay-off for human development and economic growth, with immediate visible short-term gains.

In 2013, a UN brief on water security warned that *"Ecosystems are vital to sustaining the quantity and quality of water available within a watershed, on which both nature and people rely. Maintaining the integrity of ecosystems is essential for supporting the diverse needs of humans and for the sustainability of ecosystems, including protecting the water-provisioning services they provide".*

In his 2017 report on progress towards the Sustainable Development Goals (SDGs), the UN Secretary-General introduced SDG 6 by stressing that *"Access to safe water and sanitation and sound management of freshwater ecosystems are essential to human health and to environmental sustainability and economic prosperity"*.

The water-related benefits of healthy ecosystems provide a powerful illustration of the fundamental nature of ***ecosystem services***. Ecosystems provide water purification as they process and filter out pollutants and sediment when water moves through wetlands, forests and river systems – allowing for the provision of clean drinking water. Ecosystems regulate water quantity, storing and tempering the release of water thereby providing protection against water-related disasters such as floods.

However, the ecosystems we rely on for the provision of these services and many more are increasingly modified, often to the extent that their ability to deliver the water-related services on which we depend is severely reduced. SDG 6 recognizes the key importance of "sound management of freshwater ecosystems", in recognition that continued modification and degradation of our remaining healthy ecosystems is not an option and recalling the need to address the functionality of modified ecosystems.

Protecting and caring for ecosystems in a manner that allows for essential water-related services to be provided requires ***a science-based, detailed and comprehensive understanding*** of water and ecosystem dynamics. Obtaining such an understanding requires good science, drawing on multiple fields of inquiry. Ecosystem-based water services need to be streamlined into water planning and integrated water resources.

UNESCO's International Hydrological Program (IHP) developed ***ecohydrology*** as an integrative science that focuses on the dual regulation of hydrology and biota to enhance ecosystem capacity in both urban and rural environments. This paradigm concept has emerged as a trans-disciplinary approach to finding solution-oriented methods for reducing anthropogenic impacts on ecosystems. It is with the aim of reversing these impacts that ecohydrology seeks to reinforce ecosystem services in these modified landscapes.

Hydrology for Environment, Life and Policy (HELP) is a cross-cutting UNESCO initiative aimed at bridging the gap between hydrological science, legislation and river management through the establishment of demonstration river basins. A number of HELP basins such as Davao (Philippines), Indus (Pakistan), Murray-Darling (Australia) and Langat (Malaysia) are active in the Asia and the Pacific, promoting the twinning of river basins through south-south cooperation for improving water management at the river basin level.

Aiming to achieve sustainability in both ecosystems and human populations, as well as to improve ***Integrated Water Resources Management*** (IWRM), ecohydrology supports SDG 6, with particular reference to targets 6.5 and 6.6. The application of new knowledge and insight emerging from ecohydrological research has the potential to enhance IWRM, allowing policy makers and water managers to improve the resilience of freshwater ecosystems to human impacts. This in turn has the potential to place a stronger focus on water-related ecosystem services and help achieve IWRM goals with minimal engineering inputs and financial investment.

While new science-based approaches to water management are making headway towards ensuring the recognition of water-related ecosystem services, effective long-term safeguarding of ecosystems will only be realized once a broader public understanding of their essential functions has been achieved. This requires a comprehensive investment in and reorientation of water education at all levels. ***Water education*** must go beyond the teaching of hydrological sciences, and be both multidisciplinary and interdisciplinary in nature. Water education should be considered a significant component of formal primary and secondary education, and should include community education strategies to promote communitywide water conservation, as well as enhance skills in local co-management of water resources. Water education should reach out to media professionals so that they can communicate water issues accurately and effectively.

Achieving all of these will require action across multiple fronts and at multiple levels such as supporting the enhancement of tertiary water education capacities, promoting the continuous professional development of water scientists, engineers, managers and policy makers in the water sectors; as well as developing guidelines, briefing papers, prototype professional development programmes and case studies connected with water education for water security.

Through the examination of case studies from Asia and the Pacific, the contributions of new integrated and problem-oriented scientific approaches towards the maintenance of ecosystem integrity and health will be highlighted. Particular focus will be placed on approaches that draw on the contributions from multiple fields of inquiry, bringing these to bear for the resolution of challenges and conflicts relating to the management of ecosystems.

In this regard, case studies will emphasize the ***ecohydrology*** approach and its application in river basins in Asia and the Pacific. In particular, emphasis will be placed on the application of ecohydrology for enhanced recognition of ecosystem services in **IWRM.**

In addressing ***water education***, focus will be placed on the role of regional water-related centres and recent achievements, highlighting case studies of leading practices in sustainable water management developed to maintain and expand the training of technicians in water-related fields.

High Stakes in a Dynamic Environment

Water is fundamental to the post-2015 development agenda and achieving the Sustainable Development Goals (SDGs), in particular the dedicated goal for water. Yet, we face a challenging new horizon, one where the world's population will bulge to almost 10 billion by 2050 and hungry cities will require more energy and drinking water. Global water demand is projected to increase by about 55%, due to the growing needs for domestic water, manufacturing, and thermal electricity generation. Agriculture will need to produce 60% more food globally by 2050, and 100% more in developing countries, using diminishing water resources while the world gets warmer (ADB, 2016).

By 2050, more than 60% of the Asia and Pacific region's population will be living in cities. Asia is home to 13 of the world's 22 megacities, and the number is expected to go up tob 20 megacities by 2025. Yet, we are faced with a staggering 1.7 billion people lacking access to basic sanitation and almost 80% of wastewater being discharged in water bodies (rivers, lakes, and the sea) with little or no primary treatment. The water quality-related health risks are immense (ADB, 2016).

Over-engineering of the environment raises management costs and in many cases does not ensure sufficient ecological quality and services. Efforts need to be taken to develop "soft engineering" techniques to complement "hard engineering" solution. The management approach has to go beyond protection and restoration, as we need to also recognize the carrying capacity of ecosystems as find ways of improving and transferring solutions across a variety of environment.

In Environmental Sustainability, the protection and maintenance of natural functions and ecosystem components are vital in order to ensure a healthy ecosystem for human wellbeing and the sustainability of all species.

Structure of the Report

This Regional Report (Asia and the Pacific) on theme: Mobilizing Science for Healthy Ecosystems with title: Mobilizing Science for the SDGs through Enhanced Freshwater Ecosystem Management in Asia and the Pacific is presented in two parts: Part 1 presents executive summary, abstract, introduction and summaries of the topics, while Part II explores some of the water management challenges such as freshwater ecosystem, river ecosystem, forest hydrology and ecosystem, management of environmental flows, etc., with examples from Asia and the Pacific region.

This report aims to strengthen both the scientific knowledge and management on freshwater ecosystems, by drawing upon studies, research, development, and different case studies and experiences with some examples on the successes and challenges, and presenting the actions needed to strengthen cooperation and networking amongst partners and stakeholders. In so doing, it is hoped that the report may help engender further discussion on the identification of pathways to water sustainability in Asia and the Pacific. The specific themes on ecosystem are elaborated into four topics in Part II as follows:

Topic 1: Freshwater Ecosystem Health.
Topic 2: Natural River Ecology, Ecosystems and Hydraulics.
Topic 3: Managing Environmental Flows for People and Healthy Aquatic Ecosystems
Topic 4: Forest Hydrology, Ecosystem and Environmental Water Security

Topic 1

Freshwater Ecosystem Health

Mobilizing Science for Healthy Ecosystems

Ulu Bendul Recreational Park,
Negeri Sembilan, Malaysia

Topic 1

Freshwater Ecosystem Health

Summary

Rising human population and levels of socio-economic development have led to a rapid rate of water resource development and the replacement of naturally occurring and functioning systems with highly modified and human-engineered systems. Meeting human needs for freshwater provisioning services of irrigation, domestic water, power, and transport has come at the expense of inland water ecosystems; rivers, lakes, and wetlands that contribute to human well-being through recreation, scenic values, maintenance of fisheries and biodiversity, and ecosystem function.

1. Introduction

1.1 Stakes are high to effectively plan and manage the water systems due to deterioration of water quality, overexploitation of freshwater resources; hydrological hazards and sectorial management all pose a risk to human health as well as economic and social development. This also affects the functioning of ecosystems. 'Soft engineering' techniques provide cost- effective solutions that should be explored to complement 'hard engineering' solution responses.

1.2 Water security, the reliable availability of an acceptable quantity and quality of water for health, livelihoods and production, coupled with an acceptable level of water-related risks is rapidly declining in many parts of the world.

1.3 Sustainable water solutions, whether at the local, regional and global levels, require creativity, new advances in scientific knowledge, discoveries and innovations.

2. Healthy Freshwater Ecology and Ecosystem

2.1 Human intervention can also cause water movement. The surface tension of the water will also affect the organisms that occupy the area. It can affect the amount of oxygen that reaches organisms living below the water surface. These factors all affect the way of life for organisms occupying such a freshwater ecosystem. (NPTEL, n.d.). The chemical compositions of the water, soil and surrounding air also play a part in determining the face of the ecosystem.

2.2 Freshwater ecosystems provide many economically valuable commodities and services to society. These services include flood control, transportation, recreation, purification of human and industrial wastes, habitat for plants and animals, and production of fish and other foods and marketable goods. (Baron, J.S. et al, 2003). These ecosystem benefits are costly and often impossible to replace when aquatic systems are degraded.

3. Water Education in Asia and the Pacific

3.1 Integrating new research and publications, including ecohydrology and integrated water resources management (IWRM), into public education and management systems remains a challenge that has been identified by water education stakeholders in Asia and the Pacific and Africa region. Causes underlying these challenges may in some cases include bureaucratic procedures and the lack of institutional memory within the relevant government departments.

3.2. In addition to education stakeholders, water managers also play a major role in educating the public on water and thereby influencing water agenda to policy makers. An example of such role is given by Murray-Darling Basin, where free Australian Curriculum lesson plans and worksheets and interactive lessons (for teachers), and education resources including games and videos on Murray–Darling Basin and why water is so important (for students) are made available for educators to help to teach students.

3.3 In strengthening water education in the region, UNESCO Office Jakarta has played its role in Asia and the Pacific region water education which includes a multidisciplinary and interdisciplinary approach aimed to advance scientific knowledge.

3.4 An example of one project is UNESCO Office Jakarta's collaboration with University of Timor (Unimor), Indonesia throughout 2016 to promote ecohydrology concept and approaches through awareness raising program to teachers, high school students, university students and the community, and also through intervention program to polluted river in order to increase the river carrying capacity. Four (4) model schools were established under close supervision of Unimor and UNESCO Office Jakarta, as pioneers for applying the syllabus and teaching materials in their schools.

3.5 *"Water Management Curricula Using Ecohydrology and Integrated Water Resources Management (IWRM)"* was completed in November 2017, targeted at higher level of education. The modular training curriculum was published by Humid Tropics Centre, Kuala Lumpur (HTCKL) under the coordination of UNESCO Office Jakarta, and disseminated among water-related Regional Centres and Chairs of UNESCO in Asia and the Pacific and Africa.

4. IRBM and IWRM

4.1 Integrated River Basin Management (IRBM) is a subset of Integrated Water Resources Management (IWRM) and is an effective approach or tool to achieve IWRM objectives at river basin level, by acknowledging river basin management as an entity, instead of as a series of individual, unconnected pieces. It is geared towards integrating and coordinating policies, programmes and practices to addresses water and water related issues. It requires improved professional capacity and increased financial, legislative, managerial and political capacity because the critical success factors for managing a river basin depend on such as in institutional partnering & function separation, constitution legislation and standards, implementation capability, participation & cooperation, conflict resolution and regulatory control, champion profiling, awareness & education, and information management and performance monitoring.

4.2 IWRM is based on the understanding that water resources are an integral component of the ecosystem, a natural resource, and a social and economic good. It is needed because IWRM will comprise management of water resources, disasters and environmental issues.

4.3 Management of the river basins must include maintaining the ecosystem to function sustainably as a paramount goal. Sustainable and effective management of water resources demands a holistic approach, which can be achieved by linking socio- economic development with the protection of natural ecosystems and considering the linkage between land and water.

5. Hydrology for the Environment, Life and Policy (UNESCO-HELP) Programme for River Basins

5.1 Hydrology for the Environment, Life and Policy (HELP) programme aim to deliver social, economic and environmental benefit to stakeholders through sustainable and appropriate use of water by directing hydrological science towards improved integrated catchment management basins. The central strategy of Global-HELP is to put in place a global network of catchments dealing with a large number of different research topics in hydrology and water resources.

5.2 In order to solve several major resource management issues in the Motueka River catchment, New Zealand a UNESCO HELP Basin since 2004 an Integrated Catchment Management (ICM) Research programme, was applied to provide information and knowledge to improve the management of land, freshwater and near- coastal environments. The programme is a multi-disciplinary, multi-stakeholder research program which includes redefined and extended catchment by considering coastal ecosystem management, fish and freshwater resources; integrated management and social cohesion; and community. Lessons learned from this project are the importance of sharing knowledge between scientific disciplines and across scientific and not scientific interests, which produced a much richer understanding of the catchment, resulting in its redefinition, facilitating greater community understanding of interactions between catchment activities and providing a mechanism to reduce social tension.

5.3 The Murray-Daring, Australia Basin Plan, developed by the Murray-Darling Basin Authority (MDBA) in collaboration with Basin States, provides a coordinated approach to water use across the Basin's four States. The Basin Plan is developed under the Water Act 2007 and represents one more step of managing both surface water and groundwater resources. It limits water use at environmentally sustainable levels by determining long-term average Sustainable Diversion Limits for both surface water and groundwater resources. The key outputs include improved collaboration between research agencies and policy making/management bodies as well as economic valuation methods for ecosystem services.

5.4 UNESCO Office Jakarta together with LESTARI, University of Kebangsaan Malaysia (UKM) has implemented a demonstration activity in Langat River Basin, Malaysia titled *"Establishment of Sustainability Science Demonstration Pilot Project on Restoring and Managing Langat River, Malaysia for Future"* during 2016-2017. The project focused on collection and collation of baseline qualitative and quantitative information in the fields of hydrology, hydrogeology, pollution sources, ecosystems and cultural preservation, emphasizing that their interaction and balance is needed in order to understand the whole socio-ecological system of the Basin. A multi- dimensional Rehabilitation and Restoration Plan and an Urban Stormwater Management Plan were developed.

6. Ecohydrology Activities in Asia and the Pacific

6.1 Ecohydrology integrates ecological sciences with the more advanced scientific fields to a great extent, including physics and mathematics of hydrology. The principles of Ecohydrology can be expressed in hydrological, ecological and ecological engineering components.

6.2 One of the activities recently supported by UNESCO: *"Ecosystem Services Economic Assessment to Understand the Economic value of Putrajaya Lake and Wetlands, Malaysia"* focused on the economic aspects by seeking to understand the value of the ecosystem services provided by the water body of the lake and wetlands. The assessment of the lake and wetlands was carried out by Perbadanan Putrajaya (Putrajaya Corporation) in collaboration with University of Putra Malaysia (UPM) and Eco Development Facilities Sdn Bhd, with the application of technical methods on the entire lake catchment. This demonstration site has contributed towards understanding the true value of all ecosystem services provided by a lake, including provisioning, regulating, cultural and other supporting services. In disseminating the results, Putrajaya Corporation in collaboration with UNESCO Office Jakarta organized a two-day international seminar on Ecohydrology Management of Putrajaya Lake and Wetlands: Ecosystem Services Economic Assessment. The participants agreed that economic valuation of ecosystem services is needed in an integrated management approach. A key outcome was the recommendation from the group that an ASEAN Lake Network (ALN) be established.

6.3 UNESCO Office Jakarta, supported a demonstration site activity *"Enhancing Resilience to Disasters of Urban Water Systems of Mindanao"* to demonstrate the resilience of the urban water systems of Davao City, Philippines by adopting a strategy that considers vulnerability and community resilience in the context of climate change. The activities include assessing the state of the urban water systems, looking into the vulnerability of the people and water supply system (WSS) infrastructure; strengthening integrated planning and coordination to enhance resilience in the management of the water systems; and raising awareness on climate change adaptation among stakeholders by demonstrating resilience.

6.4 UNESCO-IHP Initiative with Griffith University and Murray Darling Basin Authority in Developing Fit-For-Purpose Tools to Address Complex Social, Ecological and Economic Issues in Water Planning, the Murray-Darling Basin, Australia. The Australian IHP, in its national report (June 2016) reported that a 3D hydro- stratigraphy model has been developed for the Murray Basin in southeastern Australia. The model has nine layers, which represent the aquifers and aquitards in the Murray Basin.

6.5 An impact assessment of various 'what if' scenarios on water cycle and streamflows in peri-urban hydro-ecological systems, *a catchment water balance* model (Peri- Urban SimHyd) has been tested in Western Sydney, Australia catchment.

6.6 Period of drought annually occurs in the suburbs of metropolitan Beijing, China. A UNESCO-IHP Ecohydrology Programme Demonstration Project of *"Management of Regional Water Resources Linking with Managing of Wetland Biodiversity in the Suburban Area of Metropolitan Beijing, China"* has been presented as operational project.

6.7 A UNESCO-IHP Ecohydrology programme evolving demonstration project *"Linkage of wetland ecology and hydrology with the support of information techniques for assessing the degraded inland fresh water wetland habitat in Sanjiang Plain, Northeast China"* has been carried out. The Sanjiang Plain Wetlands Protection Project was evaluated successful as it increased and improved upland forest cover, restored degraded wetlands, improved wetland hydrology, increased incomes of affected households through alternative livelihoods, undertook wetland conservation education, and established wetland management capacity.

7. Water Related Centres in Asia and the Pacific

7.1 Asia-Pacific Centre for Ecohydrology (APCE), Cibinong, Indonesia, a UNESCO Category 2 Centre, has contributed to a number of programme, projects, activities, and demonstration sites that promote ecohydrology approaches for enhanced recognition of ecosystem services in IWRM such as:

a. An ecohydrology demonstration site was established in the Saguling region, specifically Cibitung River catchment aimed at demonstrating and evaluating the application of ecohydrology as well as phytotechnology in integrated river catchment management. The project results showed that the application of ecohydrology and phytotechnology measures in the Saguling Region has been successful, considering its high ownership by the local communities and authorities. This is due to the cost effective and comprehensive measures applied to address environmental concerns (water quantity and quality issues), which considered the following principles: hydrological, ecological, ecotechnological, and cultural.

b. A demonstration site *"Study on the Implementation of Ecohydrology Approach and Avoided Deforestation in Peatland Rewetting and Conservation in Ex- Mega Rice Project in Central Kalimantan, Indonesia"* has contributed towards research on sustainable peatland management using ecohydrology approach, by identifying hydrologic regimes of the peatland in order to fully understand soil character, assess plant suitability, and recommend approaches and actions to ensure peatland management that is sustainable. This collaborative research project was implemented during 2015-2016 by APCE, Research Centre for Limnology (LIPI), University of Palangkaraya, University of Lambung Mangkurat, Balai Penelitian Rawa of the Ministry of Agriculture, and Balai Rawa of the Ministry of Public Work and Housing.

7.2 International Centre for Water Hazard and Risk Management, Japan (ICHARM), a UNESCO Category 2 Centre, has developed a next-generation river discharge measurement system that ensures precisions, highly reliable measurements with automated measurement for better understanding on river systems. Pakistan is one of the countries benefitting from the technical expertise of ICHARM on river discharge measurement, with UNESCO's support where a hands-on training on river discharge measurements reflecting boat navigational skills and equipment understanding had been delivered by ICHARM.

7.3 Humid Tropics Centre Kuala Lumpur (HTCKL), Malaysia, also a UNESCO Category 2 Centre, has successfully developed software Decision Support System (DSS) for Integrated Stormwater Management Ecohydrology in collaboration with a team of lecturers and researchers from University of Tenaga National, Malaysia (UNITEN). The Integrated Stormwater Management Ecohydrology Design Aid and Database System is computer design support to optimise the performance of storm water Best Management Practices (BMPs) as it is strongly dependent on specific site criteria including type of land use, hydrological data and maintenance frequency. The objective is to assist engineers and authorities to select the most appropriate strategy for storm water BMPs trapping stormwater pollutants in urban area during construction and post-construction.

1. Introduction

At present, problems involving water, such as water shortages, water pollution and flooding arise in various parts of the world. With future increases in population, problems relating to water are expected to be aggravated and become one of the largest environmental problems globally in this 21st century. Water is generally accepted as the most important natural resources. Water is a critical input in agriculture, industry, urban area and essential to the well-being of households. Water allocation and management are often a source of conflict among nations, among social groups (particularly between urban and rural), and among sub- national regions (e.g. between water surplus and water deficits regions, and between highly industrialized and more rural or tourist oriented regions). Stakes are high to effectively plan and manage the water systems.

The deterioration of water quality, overexploitation of freshwater resources, hydrological hazards and sectorial management pose a risk to human health as well as economic and social development. This also affects the functioning of ecosystems and their ability to provide goods and services on which human well-being depends. Increase in land development has the potential to increase the volume of stormwater hence runoff that can contribute to drainage and flooding problems. (HTCKL and UNESCO Office Jakarta, 2017a)

Existing solutions in water management are based largely on a technical approach which often does not consider the functioning of the ecosystems. This over-engineering of the environment raises management costs and in many cases does not ensure sufficient ecological quality and services. Efforts need to be taken to develop 'soft engineering' technologies to complement 'hard engineering' solution.

2. Statement on Water Security

Water security is the capacity to provide sufficient and sustainable quantity and quality of water for all types of water services and protect society and the environment from water- related disasters.

Water security, the reliable availability of an acceptable quantity and quality of water for health, livelihoods and production, coupled with an acceptable level of water-related risks is rapidly declining in many parts of the world. It goes far beyond the capacity of a population to ensure that they continue to have access to potable water. Issues such as flood, deforestation, drought, water waste, high population, urbanization, solid waste disposal, chemical waste disposal and other issues are common (UNESCO-IHP, 2012a).

Sustainable water solutions, whether at the local, regional and global levels, require creativity, new advances in scientific knowledge, discoveries and innovations. Innovation geared towards sustainable development has the potential to lift economic growth, create jobs, and boost inclusive social development while at the same time contributing to water protection and conservation. (HTCKL and UNESCO Office Jakarta, 2017a)

Under the natural science, the solution could be through stormwater management control at point source, best management practices, adopting green technology such as through Integrated Catchment Management Plan (ICMP), Integrated River Basin Management (IRBM), Integrated Water Resources Management (IWRM) and Ecohydrology. While under the social science, it could be through stakeholders' engagement, community participation, through water education, cooperation and networking approach (HTCKL and UNESCO Office Jakarta, 2017a). The schematization of the process of putting science into action is shown in Figure 1.

UNESCO's International Hydrological Program's on Ecohydrology Demonstration Projects and HELP river basins networks are two innovative approaches, dealing with anthropogenic impacts and increasing variability caused by climate change, which involve engineering- based tools that integrate basin-wide human activities and changes in the hydrological cycle in order to sustain, improve and restore ecological functions and services in river basins as a basis to support positive socio-economic development (HTC KL and UNESCO Office Jakarta, 2017a).

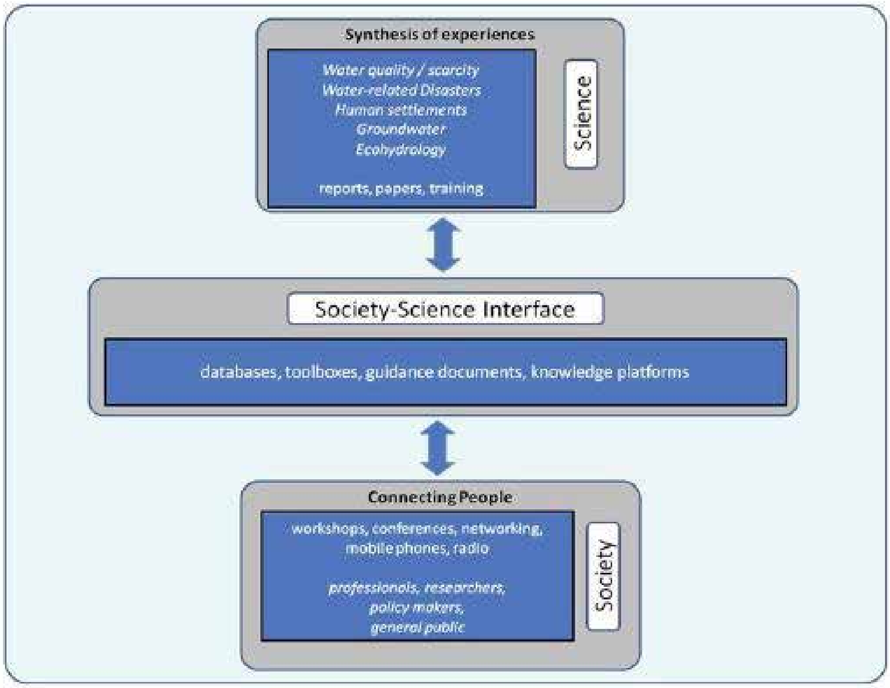


Figure 1: Simple schematization of the process of putting science into action (UNESCO-IHP, 2012a)

3. Water Education Activities for Sustainable Development in Asia and the Pacific

Water education is key to achieve Sustainable Development Goals (SDGs). Some limitations with the existing water education include use of outdated, biased or irrelevant information; poor medium of instruction; lack of continuity between different levels of water education; lack of integration with the wider curriculum and with local knowledge; lack of practical relevant to local and community needs; lack of resources; and poor linkage with local professional bodies (UNESCO-IHP, 2012b).

Water and Sustainable Education focused on an integrated understanding of biological and hydrological processes at a catchment scale in order to create a scientific basis for a new, cost-effective and systemic approach to the sustainable management of freshwater resources. Education about water issues will have to occur at all levels to equip people with the knowledge, skills and values to play a role in protecting the resource (UNESCO-IHP, 2012b).

To meet challenges in water issues, efforts should continue to be made to improve and update water education at all levels. Water education must be interpreted in a broader sense than the teaching of hydrological sciences and related scientific disciplines. UNESCO Office Jakarta has played a major role in Asia and the Pacific region. Water education, which includes a multidisciplinary and interdisciplinary approach, aimed to advance scientific knowledge through the training of sub-professionals, professionals, academia, students, community, etc. (UNESCO-IHP, 2016)

Water education also entails working with mass and community media professionals to improve their capacities to communicate water issues accurately and effectively. In addition, the programme includes community education strategies to promote community-wide water conservation, as well as skills in local co-management of water resources. (UNESCO-IHP, 2016)

Some examples of water education activities in Asia and the Pacific are presented below.

3.1 Water Education in East Nusa Tenggara, Indonesia

Most regions in East Nusa Tenggara suffer from water scarcity problems (Yustiningsih, 2017). As highlighted by Yustiningsih (2017), available studies show that the main issues of East Nusa Tenggara are "the availability of clean water during dry season, the damage of ecosystem and biota in the catchment areas and community behavior related to water and environment management".

Against this background, United Nations Educational, Scientific and Cultural Organization (UNESCO) Office Jakarta, in collaboration with University of Timor (Unimor), conducted "Integrated Water and Environmental Management for Water Sustainability Program in East Nusa Tenggara". This programme promotes ecohydrology concept and approaches through awareness raising activities to teachers, high school students, university students and the community. Further to this, an intervention programme was conducted in polluted river to increase the river carrying capacity. The activities, implemented in August 2016 until February 2017, consisted of a series of workshops to promote the integration of ecohydrology on to teaching materials and syllabus and development of teaching materials to simplify the ecohydrology dual regulation concept into school context, and using the integrated *Science, Environment, Technology, and Society* (Salingtemas) learning tool. The draft syllabus was then introduced to stakeholders through a Stakeholders Round Table Meeting.

In addition, a small-scale intervention to Oemanu river, which is polluted by tofu home- industry, was carried out to reduce the pollutants. This effort was followed by awareness raising programme for the tofu home-industry owners, and students on how to maintain river carrying capacity. EM4 (effective microorganism) was used to degrade liquid waste to decrease Biological Oxygen Demand (BOD) parameter, which successfully decreased from 2039 ppm to 341.8 ppm. The Chemical Oxygen Demand (COD) and Total Suspended Solid (TSS) have increased, but the amount can still be discharged to the environment.

Furthermore, four (4) model schools were established under close supervision of Unimor and UNESCO Office Jakarta, as pioneers for applying the syllabus and teaching materials. During monitoring period, two high schools (Taekas Senior High School and Neonbat Junior High School) have incorporated the syllabus in their academic programme. For Taekas Senior High School, ecohydrology concept has been integrated in the school curriculum. The school also encouraged students to create own activities related to water management using the ecohydrology concept. Furthermore, ecohydrology is currently being organized as compulsory course in Biology Department in University of Timor.

This programme has directly benefited 41 high school teachers, 250 university students, 10 lecturers and 20 people around demonstration site location. The activities above have contributed to: (1) Improving the understanding of ecohydrology concept among teachers through workshops and the general lecture; (2) Ecohydrology education through the development of syllabus and the teaching materials which apply ecohydrology and dual regulation concept, at the same time ensuring its ownership through stakeholders' involvement in drafting the materials; (3) Enhancing the awareness of students on environment and water management particularly in targeted schools; and (4) Enhancing public awareness and tofu home-industry owners on their role in managing river carrying capacity.

3.2 Water Management Curricular in Applying Ecohydrology Principles and IWRM Guidelines

The Modular Training Curriculum *"Water Management Curricula Using Ecohydrology and Integrated Water Resources Management (IWRM)"* for Asia and the Pacific and Africa has been developed by the Regional Humid Tropics Hydrology and Water Resources Centre for Southeast Asia and the Pacific (HTCKL) as a UNESCO Category II Centre for Hydrology and Water Resources, with the support from UNESCO Office Jakarta. The modular has also been disseminated among universities and UNESCO Category 2 Centres and Chairs in the region. The modular was the result of consultations with a consortium of Malaysian universities as well as other stakeholders. Coverage of the curricula is as below:

1. Overall Coverage

The programme is supported by UNESCO Office Jakarta to promote sustainable water resources development and management, targeted for developing and countries in Asia and the Pacific and Africa regions. This programme focused on developing modular curricular water education and strategies in watershed management through various topics & activities related to Ecohydrology principles and IWRM guidelines for sustainable water resources development.

2. Other Coverage

- To complement the IWRM Modular Curricula for Tertiary, Technical and Vocational Education, produced by UNESCO Category II Regional Water Centre - National Water Resources Institute (RW-NWRI) Kaduna, Nigeria and partners in 2012
- Target Groups: (1) Primary Group: Policy Makers, Sub-professional and Professional from Governments (federal; states) and Private Sectors, Academia, Students; (2) Secondary Group: Local Authorities
- Full coverage write-up for each of the topics
- Summary of the 'learning outcome' at the beginning of the write-up
- Focus on safe guard and enhancement of surface freshwater ecosystem, especially for watershed river basin management: (1) Primary function: surface water resources management (2) Secondary function: as water conveyance, storage and sediment transport

The curriculum provides the necessary teaching materials on different areas of water management, including freshwater ecosystem, storm water management, erosion and sedimentation, landslides, mudflow, highlands drainage, river behavior and hydraulics, morphology, among others. The curricula are targeted for practitioners, trainers, students, and other relevant stakeholders.

The curriculum was published in three (3) Volumes:

- Volume 1 consists of topics on Freshwater Ecosystem, River Ecosystem, Lake Ecosystem, and Understanding Lake Environment Management and Expert System Monitoring and two (2) Annexes, i.e., (a) Langat River Watershed Sustainability Index: Stakeholders consultation on Proposed Langat-HELP Riverfront Community Park; and (b) River Ecosystem, Integrated River Basin Management (IRBM), Integrated Water Resources Management (IWRM) in the Enhancement of Water Resources.
- Volume 2 consists of topics on Highland Drainage, Debris and Mud Flow, Sediment Erosion and Landslide Control; Erosion and its Effect; Phytoremediation Technique in River Water

Quality Improvement; Stormwater Management Ecohydrology; and Integrated Stormwater Management Ecohydrology (ISME) Small Demonstration Project at HTCKL.

- Volume 3 consists of topics on Introduction to Natural Channel (River) Hydraulics and Behavior; Hydraulic Principles Governing Flow and Regulation of River Flows; Stream Stability, Riverbank Erosion, Failure and Approaches for Riverbank Protection; Flood Control, Flow Routing and Channelization; Morphometric Analysis of River System; Sensitivity of Flood Hydrographs to Different Rainfall Distributions Profile based on a Case Study; and Introduction to Education for Sustainable Development (HTCKL and UNESCO Office Jakarta, 2017a, 2017b, 2017c).

The curricula development had involved 150 participants, through workshop "Comparative Studies of Applying Ecohydrology and IWRM for Upscaling Water Security in Asia and the Pacific and Africa" on 7-9 March 2016 in Kuala Lumpur, Malaysia.

This workshop aimed to disseminate key requirements of the Curricular Modules for the adaptation of the planning, implementation and what have been done at the national level in the Asia and the Pacific and Africa regions. It also provided a platform for knowledge sharing and learning in developing curricular modules. Firstly, these curricular and modules have provided a deeper understanding of national efforts to devise and implement effective adaptation education plans of various education levels. Secondly, approaches and technologies related to Ecohydrology and IWRM assessments, as well as resources and assistance for adaptation planning shall be involved by the government, stakeholders and NGOs through implementation organization and project-based. The implementing tools, technologies, technical assistance programmes and other approaches to Ecohydrology and IWRM for the water education adaptation will be shared. Next, detail information on modules such as methods and procedures were provided in this workshop. Collective needs and challenges in adaptation planning and for assistance on Ecohydrology and IWRM education assessments were identified through sectoral business breakout group discussions.

In this workshop, experiences and lessons learnt from curricular studies of module processes, as well as implementation of relevant actions in the Asia and the Pacific and Africa region were discussed. As a result, the participants obtained better understanding of: coordination among relevant stakeholders; mainstreaming of adaptation into development plans and budgets at national, sectorial, and local levels; linkage between government and non-governmental organization through implementation of project-based adaptation; and specific cases of adaptation planning in sectors focusing on Ecohydrology and IWRM (HTCKL and WRCSAP, 2016). Figures 2 to 5 show some activities and site visits during this event.

Figure 2: Organizer and speakers (after HTCKL and WRCSAP, 2016)

Figure 3: Some of the participants (after HTCKL and WRCSAP, 2016)

Figure 4: Groups discussion (after HTCKL and WRCSAP, 2016)

Figure 5: Site visit Public Outreach Programme (after HTCKL and WRCSAP, 2016)

The final curricula were launched in the final workshop “Pathway towards Improved Water Education Curricula” in November 2017. It was recognized in the final workshop discussions that there are certain challenges in bringing research and publications, including potentially the education curricula itself, into Government system for widespread adoption, due to the bureaucracy and the lack of institutional memory within Government. Nevertheless, the workshop concluded with the commitment of the centres, the universities, and IHP committee, within their own professional capacity and affiliations, to promote the education curricula both into the Government and outside of the Government. Figures 6 to 8 show some of the activities during the workshop.

Figure 6: Speakers and participants in the Workshop

Figure 7: Presentation through Skype from NARBO, Japan representative

Figure 8: Distribution of the curriculum

3.3 Murray-Darling Basin Educational Resources

Free Australian Curriculum lesson plans, worksheets, and interactive lessons (for teachers), and education resources including games and videos on Murray–Darling Basin and why water is so important (for students) are available in the website (https://www.mdba.gov.au/education).

For educators, some of the resources are made available as teaching materials are as follows:

The Murray–Darling Basin (years 5 and 7); The water cycle (years 6, 7 and 8); Drought and flood (years 5, 6 and 7); Water quality (years 6, 7 and 9); Salinity (years 7, 8 and 9); Running the rivers (years 5, 6 and 7); Locks, weirs and dams (years 5 and 7); European colonization of the Basin (years 5 and 7), etc.

This programme is the initiative of Murray–Darling Basin Authority (MDBA).

4. Understanding Freshwater Ecology[1]

Freshwater ecology is a study of organisms and the environment. Unlike biology, ecology refers to the study of not just organisms but how they react, and are affected by the natural surrounding environment or ecosystem. By studying the plants and animals in a body of water, as well as the components of the water itself, a scientist specializing in freshwater ecology can discover vital information about the health and needs of a freshwater system. Freshwater Ecology is a study of the interrelationships between freshwater organisms and their natural and cultural environments.

In studies of the ecology of freshwater rivers, habitats can be classified as upland and lowland. Upland habitats are cold, clear, rocky, fast flowing rivers normally in mountainous areas. Lowland habitats are warm, slow flowing rivers found in relatively flat lowland areas, with water that is frequently colored by sediment and organic matter. Classifying rivers and streams as upland or lowland is important in freshwater ecology as the two types of river habitat are quite different, and usually support very different populations of fish and invertebrate species.

There are four (4) main constituents of the living environment that form the freshwater ecosystem, they are as follows:

[1]This chapter is primarily drawn from NPTEL (n.d.)

1. Elements and Compounds of the ecosystem that are absorbed by organisms that is required as a food source or for respiration. Many of these compounds are required by plants and passed along the food chain.
2. Plants which are autotrophic by nature, meaning that they synthesize food by harnessing energy from inorganic compounds (done through photosynthesis and the sun). These plants (and some bacteria) are the primary producers, as they produce (and introduce) new energy into the ecosystem.
3. Consumers which are the organisms that feed on other organisms as a source of food.
4. These may be primary consumers who feed on the plant material or secondary consumers who feed on the primary consumers.
5. Decomposers attain their energy by breaking down dead organic material (detritus), and during this reaction, release critical elements and compounds, which in turn are required by plants.

Naturally, a river will have water movement as water succumbs to gravity and moves downstream. These are relatively constant factors that affect water movement though, for example, human intervention can also cause water movement. The surface tension of the water will also affect the organisms that occupy the area, depending on the cohesion of water at the surface; it can affect the amount of oxygen that reaches organisms living below the water surface.

These factors affect the way of life for organisms occupying such a freshwater ecosystem. On a more molecular level, the chemical compositions of the water, soil and surrounding air also play a part in determining the face of the ecosystem.

5. Sustaining Healthy Freshwater Ecosystems

Natural resource problems within river basin usually are caused by many natural and human-related factors or events. River plays a great role in controlling ecological conditions. The basin (or watershed) includes the land area that drains to a stream and is the accepted fundamental land unit for studies of river ecology (Petts, 1989). Geology, climate, and vegetative cover regulate ecosystem processes in river basins (Resh et al., 1988). Average stream flow, flow variability, velocity, stream morphology, and water quality gradually change along longitudinal stream gradients (Leopold et al. 1964; Vannote et al. 1980; Minshall et al. 1985; Ward 1989).

The following three general ecosystem features are commonly used for their value in characterizing ecosystem health (Cairns 1977; Rappaport 1989; Grumbine 1994):

1. The ecosystem supports habitats and viable native animal and plant populations similar to those present before any disturbance.
2. The ecosystem is able to return to its pre-existing condition after a disturbance, whether natural or human-induced.
3. The ecosystem is able to sustain itself.

Disturbance can be defined as an event that disrupts biology at the ecosystem, community, or population level (Pickett and White 1985; Resh, et al. 1988; Sparks, et al. 1990). A disturbance can be temporary or permanent and can result from natural processes or human activity.

Freshwater is vital to human life and economic well-being, and societies extract vast quantities of water from rivers, lakes, wetlands, and underground aquifers to supply the requirements of cities, farms, and industries. Our need for fresh water has long caused us to overlook equally vital benefits of water that remains in stream to sustain healthy aquatic ecosystems. Freshwater ecosystems provide many economically valuable commodities and services to society. These services include flood control, transportation, recreation, purification of human and industrial wastes, habitat for plants and animals, and production of fish and other foods and marketable goods. These ecosystem benefits are costly and often impossible to replace when aquatic systems are degraded. For this reason, deliberations about water allocation should always include provisions for maintaining the integrity of freshwater ecosystems. Scientific evidence indicates that aquatic ecosystems can be protected or restored by recognizing the following (Baron, et al., 2003):

- Rivers, lakes, wetlands, and their connecting ground waters are literally the "sinks" into which landscapes drain. Far from being isolated bodies or conduits, freshwater ecosystems are tightly linked to the watersheds or catchments of which each is a part, and they are greatly influenced by human uses or modifications of land as well as water. The stream network itself is important to the continuum of river processes.

- Dynamic patterns of flow that are maintained within the natural range of variation will promote the integrity and sustainability of freshwater aquatic systems.

- Aquatic ecosystems additionally require that sediments and shorelines, heat and light properties, chemical and nutrient inputs, and plant and animal populations fluctuate within natural ranges, neither experiencing excessive swings beyond their natural ranges nor being held at constant levels.

The failure to provide for these natural requirements can results in loss of species and ecosystem services in wetlands, rivers, and lakes. Scientifically defining requirements for protecting or restoring aquatic ecosystems, however, is only a first step. New policy and management approaches will also be required. Current piecemeal and consumption-oriented approaches to water policy cannot solve the problems confronting our increasingly degraded freshwater ecosystems (Baron, et al., 2003).

Freshwater ecosystems differ greatly from one another depending on type, location and climate but nevertheless share important features. The structure and functioning of freshwater ecosystems are also tightly linked to the watersheds or catchments of which they are apart. Water flowing through the landscape on its way to the sea moves in three dimensions, linking upstream to downstream, stream channels to floodplains and riparian wetlands and surface waters to ground water. There are five dynamics environmental factors that regulate much of the structure and functioning of any aquatic ecosystem, although their relative importance varies among aquatic ecosystem types. The interaction of these drivers in space and time defines the dynamic nature of freshwater ecosystems (Baron, et al., 2003):

1. The flow pattern defines the rates and pathways by which rainfall and snowmelt enter and circulate within the river channels, lakes, wetlands and connecting ground waters and also determine how long water is stored in these ecosystems.

2. Sediment and organic matter inputs provide raw materials that create physical habitat structure, substrates and spawning grounds and supply and store nutrients that sustain aquatic plants and animals.

3. Temperature and light characteristics regulate the metabolic processes, activity levels and productivity of aquatic organisms.

4. Chemical and nutrient conditions regulate pH, plants and animal productivity and water quality.

5. The plant and animal assemblage influences ecosystem processes rates and community structure.

Flow pattern is an evaluation of the characteristics required for healthy functioning can begin with a description of the natural or historical flow patterns for streams, rivers, wetlands and lakes. Certain aspects of these patterns are critical for regulating biological productivity. The characteristics flow pattern of a lake, wetland or stream critically influences algal productivity and is an important factor to be considered when determining acceptable levels of nutrient runoff from the surrounding landscape (HTCKL and UNESCO Office Jakarta, 2017a).

6. Integrated Water Resources Management

At the 2002 World Summit on Sustainable Development (WSSD) held in Johannesburg, delegates concluded that Integrated Water Resources Management (IWRM) and Water Efficiency Planning should be an essential element in all national or regional development strategies by 2005, added this target to the list of Millennium Development Goals (MDGs). Currently, IWRM is continued to be promoted and applied in Sustainable Development Goals (SDGs) to achieve target by 2030. Indeed, over the years it has been shown that an integrated approach to water resources management (IWRM) will be critical for achieving many of the SDGs, including not only those related to health, but also to poverty and hunger eradication, education, women's empowerment, environmental sustainability and global partnership for development. It is now recognized that inherent in the concept of IWRM are the principles of water-use efficiency, equity of access, a balance of competing uses, the application of all appropriate environmentally sound technology, and participatory planning and implementation to include all sectors of the economy and all segments of society.

IWRM is a cross-sectoral policy approach, designed to replace the traditional, fragmented sectoral approach to water resources and management that has led to poor services and unsustainable resource use. IWRM is based on the understanding that water resources are an integral component of the ecosystem, a natural resource, and a social and economic good (GWP, 2000).

IWRM is a process which promotes the co-ordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems (GWP, 2002). IWRM is shifted from supply oriented mono-sectoral approach to demand oriented multi-sectoral approach (Figure 9).

Figure 9: IWRM from supply mono-sectoral to demand multi-sectoral approach

It is a holistic approach that seeks to integrate the management of the physical environment within that of the broader socio-economic and political framework.

The river basin approach seeks to focus on implementing IWRM principles on the basis of better coordination amongst operating and water management entities within a river basin, with a focus on allocating and delivering reliable water-dependent services in an equitable manner (NARBO and UNESCO-IHP, 2009).

There are many success stories such as through using the concept of Spiral Model (the evolving and dynamic nature of the IWRM process) as recommended by UNESCO-IHP, involving four elements key for success which are recognizing/identifying (pressing issues or needs); conceptualizing (the problem itself and formulating possible solutions); coordination and planning (among stakeholders in order to reach an agreement); implementing/monitoring/evaluating (the plan and its outcome) as shown in Figure 10. The recommended interaction between the river basin approaches at different administrative levels is shown in Figure 11.

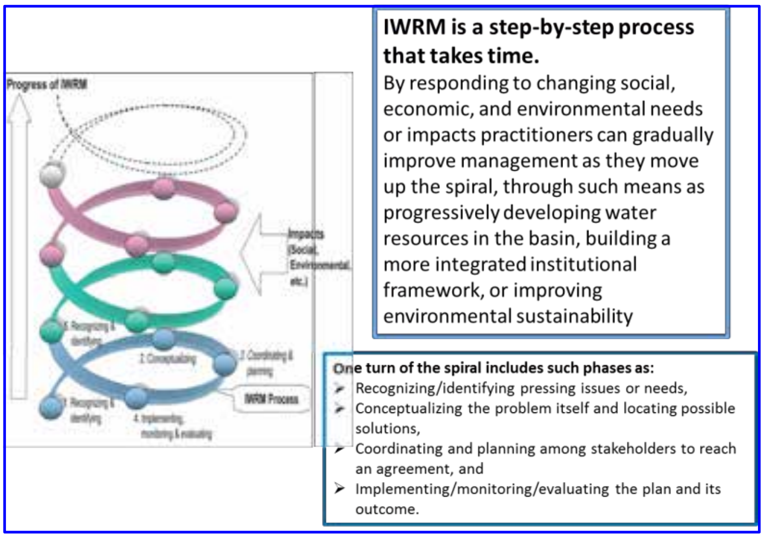


Figure 10: The Spiral Model, the evolutionary and adaptive implementation of the IWRM Process (after NARBO and UNESCO-IHP, 2009)

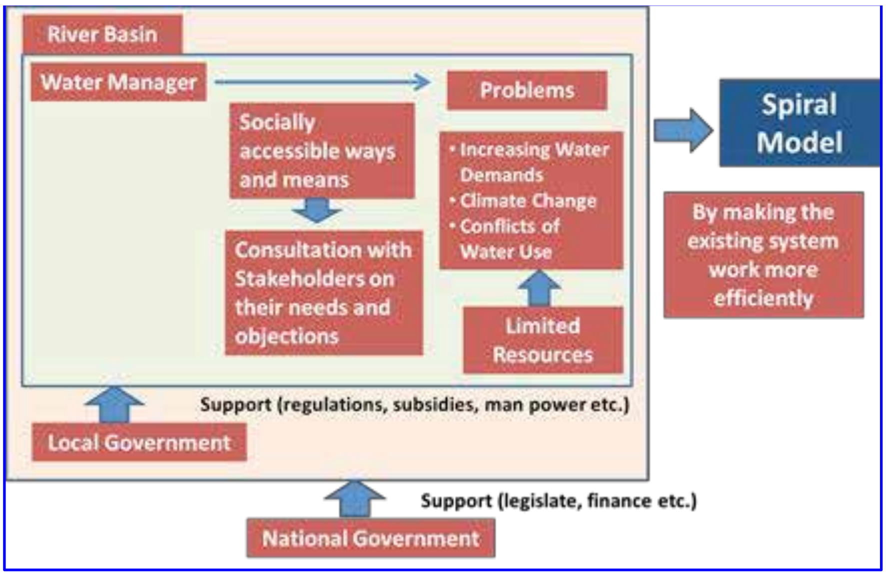


Figure 11: Interaction between the River Basin Approach at Different Administrative Levels (after NARBO and UNESCO-IHP, 2009; HTCKL and UNESCO Office Jakarta, 2017a)

6.1 What is IWRM?

The basis of IWRM is that different uses of water are interdependent. The goal is the sustainable management and development of water resources. It is a step-by-step process of managing water resources in a harmonious and environmentally sustainable way by gradually uniting stakeholders and involving them in planning and decision-making processes, while accounting for evolving social demands due to such changes as population growth, rising demand for environmental conservation, changes in perspectives of the cultural and economic value of water, and climate change. It is an open- ended process that evolves in a spiral manner over time as one move towards more coordinated water resources management (NARBO and UNESCO-IHP, 2009; HTCKL and UNESCO Office Jakarta, 2017a).

6.2 Why is IWRM Needed?

Water is a resource that is essential for economic growth and environmental and social well- being. Because it affects everyone, managing this precious resource requires balancing the interests of the many different user groups and individuals. Without that balance, many conflicts can occur. Promoting coordinated water resources management in a basin that is open to all stakeholders will not only resolve such conflicts but will also bring enormous benefits to society, the basin, and to individual stakeholders. Thus, IWRM will comprise management of water resources, disasters and environmental issues. (NARBO and UNESCO- IHP, 2009)

IWRM is about managing competing uses across interests and sectors and by building compromises through stakeholder participation (Figure 12). Benefits of IWRM to the sectors include agriculture, water supply and wastewater, mining and industry, environment, fisheries, tourism, energy, transport, etc. Each of the water uses identified has valuable positive impacts. Most also have negative impacts, which may be made worse by poor management practices, lack of regulation or lack of motivation due to the water governance regimes in place. The obvious social and economic benefits from water use sectors include food production, energy production, drinking water, jobs, recreation, etc. However, the relative value of these benefits is more difficult to assess (HTCKL and UNESCO Office Jakarta, 2017a).

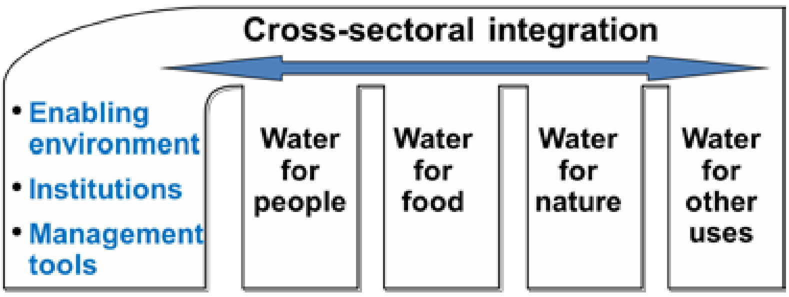


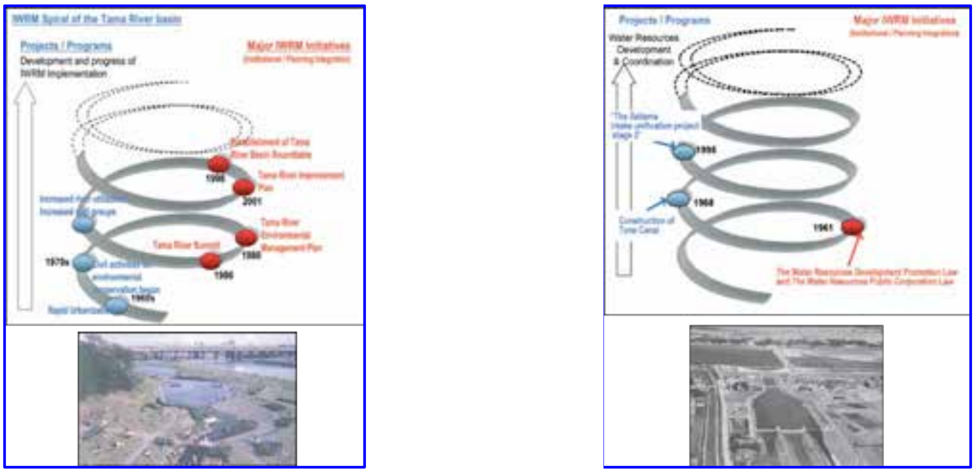
Figure 12: IWRM managing competing uses across interests and sectors

6.3 IWRM at River Basin Level

IWRM at the river basin level is a process that leads to water security and helps mitigate water-related risks (such as floods and droughts). IWRM strives for effective and reliable delivery of water services (such as municipal and industry water supply, waste water management, agriculture uses, and hydropower) by coordinating and balancing the various water-using sectors. Water security is the capacity to provide sufficient and sustainable quantity and quality of water for all types of water services and protect society and the environment from water-related disasters (UNESCO-IHP, 2012b).

It is a holistic approach that seeks to integrate the management of the physical environment within that of the broader socio-economic and political framework. The river basin approach seeks to focus on implementing IWRM principles on the basis of better coordination amongst operating and water management entities within a river basin, with a focus on allocating and delivering reliable water-dependent services in an equitable manner (NARBO and UNESCO- IHP, 2009).

IWRM involves Integrated Watershed Management coordinated planning and management of water resources of a watershed considering the interaction with the land, water and other environmental resources for their equitable, efficient and sustainable use from the local level (micro-watershed) to the national and transboundary watershed. Examples of the use of the IWRM spiral model are shown in Figures 13 and 14.



(a) Tama River, Japan **b) Tone Canal (Tone Barrage), Japan**

Figure 13: Example of Spiral Model used at river basin level

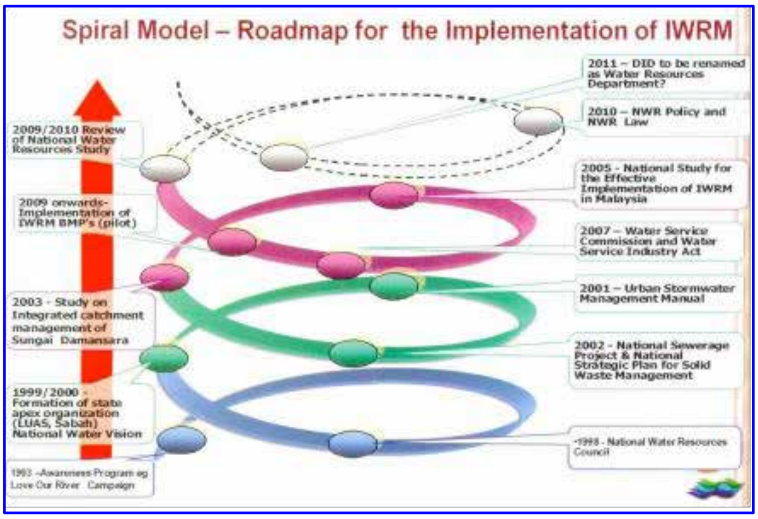


Figure 14: Roadmap for the Implementation of IWRM in Malaysia (after Selamat, 2001)

7. Integrated River Basin Management

Integrated River Basin Management (IRBM) is the process of coordinating conservation, management and development of water, land and related resources across sectors within a given river basin, in order to maximize the economic and social benefits derived from water resources in an equitable manner while preserving and restoring freshwater ecosystems (GWP, 2002). Figure 15 shows the IRBM vision. IRBM is thus a subset of IWRM and is the effective approach or tool to achieve IWRM objectives on the river basin basis. In simple terms, it is the management of a river basin as an entity (Figure 16), not as a series of individual, unconnected pieces. It is geared towards integrating and coordinating policies, programmes and practices. It addresses water and water related issues. It requires improved professional capacity and increased financial, legislative, managerial and political capacity.

Figure 15: IRBM vision (after DID, 2009; Roseli, 2016)

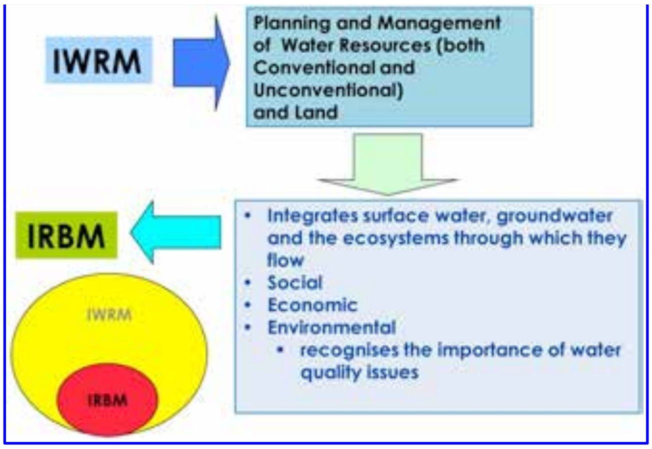


Figure 16: Relationships between IRBM and IWRM (after Roseli, 2016)

Management of the river basins must include maintaining the ecosystem to function as a paramount goal. At the same time, the sustainable and effective management of water resources demands a holistic approach, linking socio-economic development with the protection of natural ecosystems and appropriate management links between land and water uses. A river basin is a dynamic system over space and time involving many interactions between land and water bodies. Thus, attempts are needed to improve the functioning of the river basin as a whole rather than simply fixing the local problems.

The international community, through the 1992 UNCED Earth Summit, had agreed to adopt eight guiding principles for sustainable development that are relevant and are progressively being recognized as "Best Practice" principles. These Principles are (DID, 2009):

1. River Basin Based Strategies: The best practice in managing rivers and water resources is based on geographical river basins or water catchments.

2. Towards Sustainable Development: Overcoming the problems of depleting water resources, droughts, floods sedimentation and pollution, through water conservation and responsible management.

3. Integrated and Multi-functional Approach: Integrated and multi-functional approach ensures the availability of resources for all users through co-ordination and co- operation.

4. Separation of Regulatory and Service Providers Functions: Separation of functions avoids conflicting interests and allows transparency of actions.

5. Economic Value of Water and Cost Recovery: Water, resource management and pollution charges and penalties (polluters pay principle) should reflect the true economic value of the resource. The revenue should generate funds for management, protection and regulation of rivers and water resources.

6. Emerging Technologies and New Management Techniques: Effective management of the basin's resources requires leading-edge knowledge, technology and management tools. Information technology and mathematical modeling and risk assessments promote the optimization of resources development and management.

7. Stakeholder Participation: Consumers, service providers and the community at large should be involved in the decision making process and be partners in ensuring the use of best practices in resource and basin management.

8. Private Sector Participation: Privatization may be an effective means of achieving efficiency improvements or funding infrastructure and service improvements.

Figure 17 shows these principles as applied in a river basin. The critical success factors for managing a river basin are summarized in Figure 18.

Figure 17: IRBM principles in a river basin (after DID, 2009)

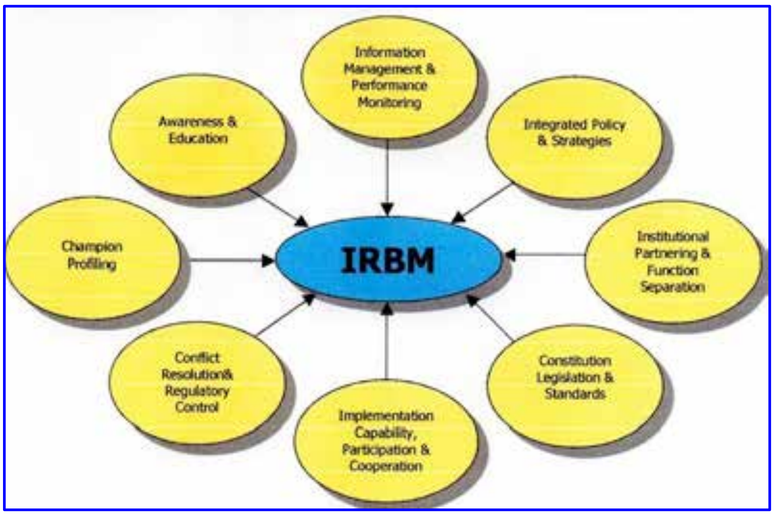


Figure 18: IRBM critical success factors (after DID, 2009)

7.1 Awareness and Education

Awareness in IWRM or IRBM can be defined as the realization or understanding of issues and components associated. It is targeted at influencing personal attitudes and effectiveness and social norms of communities in such a way that behavioral compliance for an efficient, environmental friendly and safe use of water resources is promoted, as well as social pressures towards sound and sustainable policies are stimulated. Establishing the awareness of need among the stakeholders and local community for river basin management and the education of impacts that development has on the river basin are vital to advocate their participation and involvement (DID, 2009).

7.2 Objectives of IRBM Plan

An IRBM plan for a particular river should be formulated and treated as the overall macro water resources management master plan for the river basin involving all relevant stakeholders. The main objectives of the plan shall incorporate and include the followings (DID, 2009):

- Provide clear basin water resources policies, goals, targets and objectives;
- Serves as the overall basin Strategic Plan that will provide the basis and the overall water resources strategic management for the basin; and
- Provide a plan of action for various stakeholders to achieve individual objectives of the various disciplines.

Example of proposed IRBM Plan (including suggested detailed design of identified physical projects) is given in Appendix A.

8. Hydrology for the Environment, Life and Policy (HELP) Programme for River Basins

Hydrology for the Environment, Life and Policy (HELP) is a cross-cutting and transdisciplinary initiative of UNESCO which aims to deliver social, economic and environmental benefit to stakeholders through sustainable and appropriate use of water by directing hydrological science towards improved integrated catchment management basins. The central strategy of Global-HELP is to put in place a global network of catchments dealing with a large number of different research topics in hydrology and water resources. (UNESCO, n.d.)

Some examples from international HELP river basins in Asia and the Pacific region are: Tarim River Basin and Heihe River Basin (China), Indus Basin (Pakistan), Murray-Darling Basin, Burdekin Catchment and Ord River Catchment (Australia), Langat River Basin (Malaysia), Davao Basin (Philippines), Brahmani-Baitarani Basin (India), Motueka (New Zealand), Kumho River Basin (Republic of Korea), Upper Kaligandaki (Mustang) River Basin (Nepal), and Syrdarya River Basin (shared by four countries: Kyrgyz Republic, Tajikistan, Uzbekistan, Kazakhstan).

8.1 Motueka, New Zealand

The Motueka River, a UNESCO HELP Basin since 2004, drains an area of 2,180 km2 of the Tasman District in the north of New Zealand's South Island. Over only 110 km the Motueka falls from its alpine headwaters at 1,800 m and delivers 62% of the freshwater inflow to Tasman Bay. Taman District Council (2013) in Camkin (2013) found several major resource management issues in the catchment. The issues are:

- Competition for water and the impact of water use on in-stream values,
- Impact of deposition of sediments on life in streams and coastal waters,
- High concentrations of pathogenic organisms at times in the lower catchment, and
- High water temperature and poor aquatic habitat.

In order to solve the issues, an 11-year Integrated Catchment Management (ICM) Research programme, was applied to provide information and knowledge to improve the management of land, freshwater and near-coastal environments in catchments with multiple, interacting, and potentially conflicting land uses. The programme is a multi-disciplinary, multi- stakeholder research programme. The programme includes redefined and extended catchment by considering coastal ecosystem management, fish and freshwater resources; integrated management and social cohesion; and community engagement. (Camkin, 2013)

Lessons learned from this project are the importance of sharing knowledge between scientific disciplines and across scientific and not scientific interests, which produced a much richer understanding of the catchment, resulting in its redefinition, facilitating greater community understanding of interactions between catchment activities and providing a mechanism to reduce social tension. (Camkin, 2013)

8.2 Murray-Darling, Australia

The Murray-Darling is a HELP basin which accounts for 40% of Australia's national agricultural output and it is characterized by low rainfall and high climatic variability. Main issues in the basin are:

- Falling groundwater levels and rinsing land and water salinity.
- Altered seasonality of flows has negative impacts on the environment.

Key outputs of HELP related projects in the basin include improved collaboration between research agencies and policy making/management bodies as well as economic valuation methods for ecosystem services. (UNESCO-IHP and HELP, 2010)

Based on Australian IHP National Report (2016), activities in Murray-Darling HELP Basin focused on the development of a Basin plan, the largest ever water reform in the Murray Darling Basin. The Murray-Daring Basin Plan developed by the Murray-Darling Basin Authority (MDBA), in collaboration with Basin States, was adopted on 22 November 2012, provides a coordinated approach to water use across the Basin's four States and the ACT. The Basin Plan encompasses a large body of work that the MDBA will develop, coordinate and implement through to 2024. The Basin Plan is developed under the Water Act 2007 and represents one more step in the ongoing journey of managing both surface water and groundwater resources. It limits water use at environmentally sustainable levels by determining long-term average Sustainable Diversion Limits for both surface water and groundwater resources.

The Basin Plan aims to achieve a balance between environmental, economic and social considerations. It allows for further improvements in outcomes through a sustainable diversion limits adjustment mechanism and a constraints management strategy. Also under the Basin Plan, Water Resource Plans have a fundamental role in ensuring the limits on the quantities of surface and groundwater that can be taken from the Basin will operate from 2019 and beyond. Further, the Water Quality and Salinity Management Plan provide a framework for action to protect and enhance water quality for environmental, social, economic and cultural uses. The Basin Plan includes:

- An environmental watering plan to optimize environmental outcomes for the Basin.
- A water quality and salinity management plan.
- Requirements that state water resource plans will need to comply with, if they are to be accredited.
- A mechanism to manage critical human water needs.
- Requirements for monitoring and evaluating the effectiveness of the implementation of the Basin Plan.

8.3 Langat River Basin, Malaysia

The Langat River Basin in the state of Selangor is an important water catchment area and a source of hydropower (two reservoirs and eight water treatment plants), providing raw water supply and other amenities to more than 1.59 million people. Besides water supply, Langat River is used for recreation, fishing, aquaculture, effluent discharge, irrigation and industrial activities such as sand mining.

The Langat River Basin has been recognized as a UNESCO-IHP HELP River Basin since 2004 (during the implementation phase of HELP) when it was classified as an Evolving HELP Basin. According to a project carried out in 2016-2017 by UNESCO Office Jakarta and LESTARI Universiti Kebangsaan Malaysia (UKM), the key issues of Langat River Basin were identified as follow:

- Urban storm water - untreated runoff, flooding and sullage.
- Sewage and sewerage systems – inadequate sewage system.
- Waste management – solid waste disposal, illegal dumping sites and leachate.
- Groundwater – pollution and abstraction.
- Erosion and sedimentation – land erosion and bank erosion.
- Deforestation - illegal logging, loss of forest area and rapid urbanization.
- Mining activities – sand abstraction (Figure 19).
- Fragmentation in administration - lack of responsibilities, conflict of interest in administration, lack of expertise, enforcement and river reserve encroachment.

Figure 19: River dredging activities in the area (after LESTARI UKM, 2016)

In addressing the above issues, multi-dimensional Rehabilitation and Restoration Plan and an Urban Stormwater Management Plan were developed under the project. Their five main components are:

- Enabling Environment – and the capacity of stakeholders to engage and play their respective roles in river basin and water resource management.
- Organization and Institutional Roles - and encourage River Basin Organisations (RBOs) to be a coordinator, providing linking mechanisms between various levels of stakeholders.
- Implementation Instruments.
- Education and Outreach – to build a common understanding among stakeholders of river basin or water resource management. Public outreach at every stage of water resource development and management is crucial to public participation and stakeholder commitment in implementing plans.
- Monitoring and Evaluation - Evaluation is a continuous process that takes place at all levels of the river basin and in water resource development and management.

Overall, it can be concluded that sustainable river management of the Langat River Basin could be achieved by good restoration and management practices. The recommendations put forward by the project are:

- To ensure sustainable development, water resources need to be managed in an integrated and holistic manner.
- River management becomes sustainable with good restoration and management practices.
- River restoration has taken place to some extent in Langat River Basin but challenges such as forest fragmentation, development pressure on land use, forest cover loss are still present.
- Restoring and managing rivers are integral part of Integrated River Basin Management (IRBM) implementation.

- It is possible to overcome these challenges by IRBM implementation in Langat River Basin involving social learning, collaborative decision making and a sustainability science approach.
- Research and educational programmes should be expanded to reach all relevant stakeholders, such as the public sector, the business sector, NGOs and local communities.
- Programmes for improving the Langat HELP River Basin need to be implemented, such as the Development of Langat Research Information Centre (LRIC) for Sustainability Science of the Langat River Basin.

9. Ecohydrology

Ecohydrology is a sub-discipline of ecological engineering and can be considered as one of several important ecological disciplines which contribute to build an important bridge between ecology and environmental management to so to say use our ecological knowledge to make a better environmental management (Jogensen, 2016).

In terrestrial ecosystems (such as forests, deserts, and savannas), the interactions among vegetation, the land surface, and the groundwater are the main focuses. In aquatic ecosystems (such as rivers, streams, lakes, and wetlands), emphasis is placed on how water chemistry, geomorphology, and hydrology affect their structure and function. A fundamental concept in ecohydrology is that plant physiology is directly linked to water availability. Ecohydrological theory also places importance on considerations of temporal (time) and spatial (space) relationships. Hydrology, in particular the timing of precipitation events, can be a critical factor in the way an ecosystem evolves over time.

The principles of Ecohydrology are expressed in three sequential components (Chicharo, et al., 2009):

1. Hydrological: The quantification of the hydrological cycle of a basin, should be a template for functional integration of hydrological and biological processes.
2. Ecological: The integrated processes at river basin scale can be steered in such a way as to enhance the basin's carrying capacity and its ecosystem services.
3. Ecological engineering: The regulation of hydrological and ecological processes, based on an integrative system approach, is thus a new tool for Integrated Water Basin Management.

A fundamental equation in ecohydrology is the water balance at a point in the landscape. A water balance states that the amount of water entering the soil must be equal to the amount of water leaving the soil plus the change in the amount of water stored in the soil. The water balance has four main components: infiltration of precipitation into the soil, evapotranspiration, leakage of water into deeper portions of the soil not accessible to the plant, and runoff from the ground surface.

9.1 Freshwater Ecosystem

Freshwater ecosystems are a subset of Earth's aquatic ecosystem. They include lakes and ponds, rivers, streams and springs, and wetlands. They can be contrasted with marine ecosystems, which have a larger salt content. Freshwater habitats can be classified by different factors, including temperature, light penetration, and vegetation. Freshwater ecosystems can be divided into lentic ecosystems (still water) and lotic ecosystem (flowing water). The issues are:

- Freshwater systems; lakes, wetlands, rivers and streams have been critical to the establishment of civilizations.

- Water bodies are essential to humans not only for drinking but also for transportation, agriculture, energy production, industry, and waste disposal.
- Deteriorating status of surface waters.
- To reduce municipal and industrial wastewater discharges to water bodies.
- Activities of human societies can pollute and degrade water resources.
- Risk analysis for freshwater bodies requires knowledge of how human land use affects the physical, chemical, and biological characteristics of the aquatic ecosystem.

9.2 River Ecology and Ecosystem

The ecology of the river refers to the relationships that living organisms have with each other and with their environment – the ecosystem. An ecosystem is the sum of interactions between plants, animals and microorganisms and between them and non-living physical and chemical components in a particular natural environment (Science Learning Hub, 2014).

River ecosystems have (Science Learning Hub, 2014):

- Flowing water that is mostly unidirectional.
- A state of continuous physical change.
- Many different (and changing) microhabitats.
- Variability in the flow rates of water.
- Plants and animals that have adapted to live within water flow conditions.

9.3 Lake Ecosystem

A lake could be defined as an enclosed body of water (usually freshwater) totally surrounded by land and with no direct access to the sea. A lake may also be isolated, with no observable direct water input and, on occasions, no direct inputs. A lake may also occur anywhere within a river basin (Thomas, et al., 1992).

A typical lake has distinct zones of biological communities linked to the physical structure of the lake (Figure 20). The littoral zone is the near shore area where sunlight penetrates all the way to the sediment and allows aquatic plants (macrophytes) to grow. Light levels of about 1% or less of surface values usually define this depth. The 1% light level also defines the euphotic zone of the lake, which is the layer from the surface down to the depth where light levels become too low for photosynthesizers. In most lakes, the sunlit euphotic zone occurs within the epilimnion. (WVCA, n.d.)

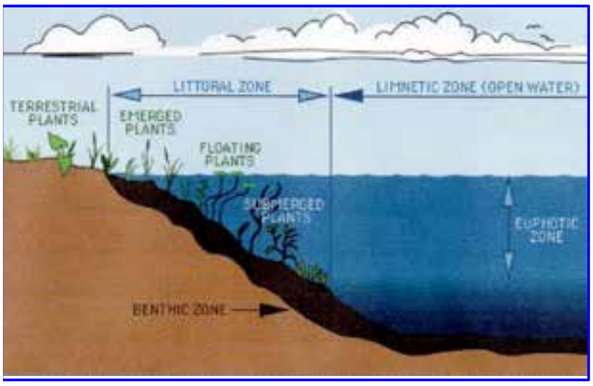


Figure 20: Zones in a typical lake (after WVCA, n.d.)

9.4 Wetlands

The Ramsar Convention (or International Convention on Protection of Wetlands, particularly as waterfowl habitat) defined wetlands as areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salty, including areas of marine water the depth of which at low tide does not exceed six metres. Wetlands are, thus, transitional habitats between dry land and deep water. They include marshes, swamps, peatlands (including bogs and fens), flood meadows, lakes and ponds, rivers and streams, estuaries and other coastal waters (including salt marshes, mangroves and even coral reefs) (Ramsar, 1971).

Wetland is an area of land where soil is saturated with water either permanently or seasonally. Such areas also need to be covered, at least partially, by shallow pools of water. Wetlands include swamps, marshes and bogs, among others. The water found in wetlands can be saltwater, freshwater or brackish. Wetlands are considered the most biologically diverse of all ecosystems. Wetland systems can be explicitly designed to aid in pollutant removal from stormwater and also provide for quantity control by providing a significant volume of temporary water storage above the permanent pool elevation. Water levels rise during rainfall events and outlets are configured to slowly release flows, typically based on the design Water Quality Volume (WQV) (DID, 2012).

As stormwater runoff flows through the wetlands, pollutant removal is achieved via settlement and biological uptake within the best management practices (BMPs). Wetlands are among the most effective stormwater BMPs in terms of pollutant removal, and also offer aesthetic value. Constructed surface flow wetlands systems remove pollutants in stormwater through sedimentation, filtration of fines and biological uptake. The main wetlands components are the inlet zone, macrophyte zone and then open water zone (Figure 21) (Lariyah, 2013).

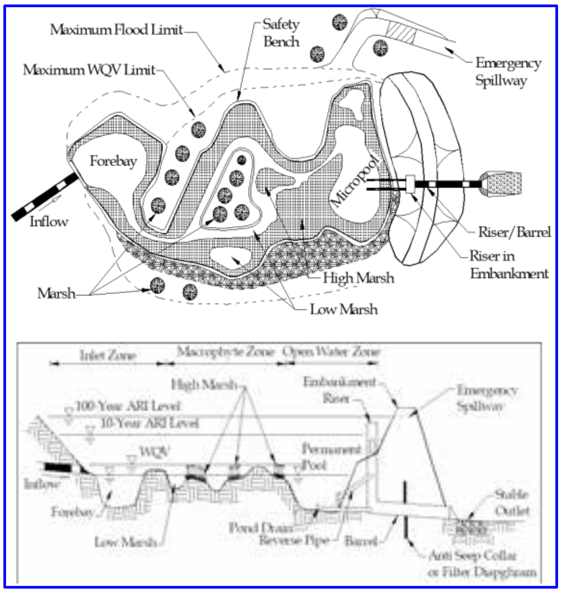


Figure 21: Wetlands component (after Lariyah, 2013)

Example of constructed wetlands is shown in Figures 22 and 23. The word 'sungai' in the figure means river.

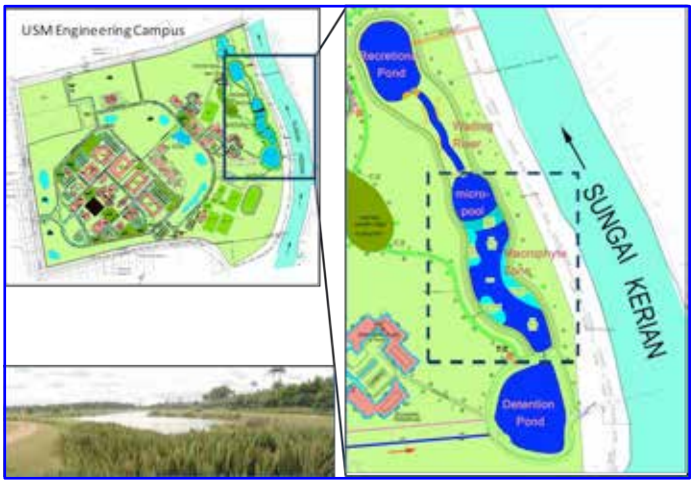


Figure 22: Stormwater Wetlands in USM Engineering Campus, Malaysia (after Lariyah, 2013)

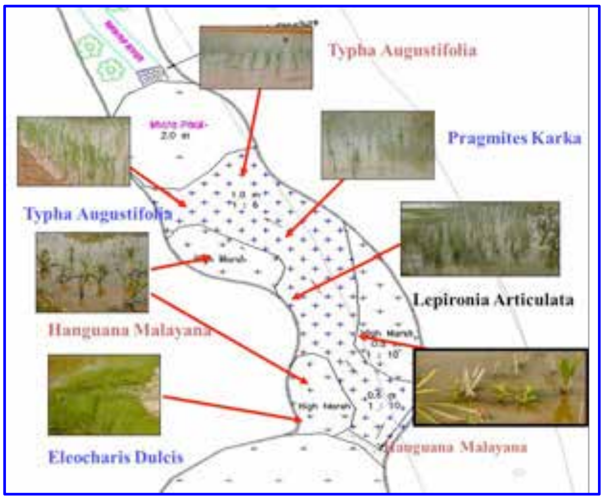


Figure 23: USM wetlands plant species (after Lariyah, 2013)

9.5 Implementation of Ecohydrology across Asia and the Pacific Region

Ecohydrology demonstration sites in Asia and the Pacific Region that have been supported by UNESCO Office Jakarta with partners, are described in following sub-section.

9.5.1 Putrajaya Lake and Wetlands, Malaysia

Putrajaya Lake and Wetlands catchment are located in Putrajaya Federal Territory within the Langat River Basin area, a UNESCO HELP river basin, in Malaysia. UNESCO recently supported an activity, called "Ecosystem Services Economic Assessment to understand the economic value of Putrajaya Lake and Wetlands" to understand the true value of all ecosystem services provided by a lake, including provisioning, regulating, cultural and other supporting services. Having the economic value of ecosystem services would further allow authorities to make well-informed environmental investment decisions in maintaining or improving the ecosystem services.

Sustainable management of the city's lake and wetland is important to ensure the well-being and livelihood of the surrounding community. In this regards, the various aspects of the surrounding ecology, environment, social, economic, legislatures, amenities, infrastructure, technology and other aspects must be taken into account.

This project focused on the economic aspects by seeking to understand the value of the ecosystem services provided by the water body of the lake and wetlands. This is necessary to determine the actual benefit that people gain and at the same time the cost that will be sacrificed, if any of its features changes in the future. The economic assessment of the lake and wetlands was done in 2015 by Perbadanan Putrajaya (Putrajaya Corporation) in collaboration with University of Putra Malaysia (UPM) and Eco Development Facilities Sdn Bhd, with the application of technical methods on the entire lake catchment of the Putrajaya Lake and Wetlands. Being a pioneer study on this subject for lakes in Malaysia, this study contributes towards understanding the value of lakes in Malaysia.

Putrajaya Lake and Wetlands is a man-made lake within the Langat River Basin. The lake and wetlands are used for recreational and relaxation for the people of Putrajaya and visitors. Using The Economics of Biodiversity and Ecosystems (TEEB) framework, the ecosystem services provided by the Putrajaya Lake and Wetlands consist of:

- Provisioning Services: water supply and fish.
- Regulating Services: flood mitigation, high water quality and diversity.
- Cultural Services: recreational, tourism events and educational activities including research.
- Supporting Services: nutrients cycle and pollination.

The valuation methods used in the study are:

- Direct Market Values (DMV) for the lake water, the values of fishes in the lake and the direct usage for boat ridership in the lake.
- Contingent Valuation Method to determine the economic values in the conservation management; Travel Cost Method to determine the economic values of the benefits from the recreational usage; and Hedonic Pricing Method to determine the economic values of the aesthetical aspects. Data was gathered through surveys.
- Benefit Transfer Approach (BTA) for other ecosystem services, using similar past economic valuation studies on various ecosystem services conducted in Malaysia.

Based on these methods, the 2015 ecosystem services value of Putrajaya Lake and Wetlands is calculated at USD 1,381,296,965.96, as in below table:

Table 1: The results of economic assessment done for Putrajaya Lake and Wetlands System

No	ITEM	ECOSYSTEM SERVICE	VALUATION TECHNIQUES	VALUE (USD)
1.	**DIRECT MARKET VALUE**			
1.1	Selling the lake water for drinking - Water Rent	Provisional	Direct Value	4,498,239.44
1.2	Use of the Cruise Putrajaya Lake boating service	Cultural	Direct value	5,675,117.37
1.3	Fish harvest	Provisional/ Cultural	Direct Market Price	1,142,394.37
			Sub Total DIRECT MARKET VALUE	**11,315,751.17**
2.	**BENEFIT TRANSFER METHOD**			
2.1	Water quality improvement	Regulating	Waste Treatment	554,773.24
2.2	Local climate influence	Regulating	Climate regulation	1,447,750.23
2.3	Nuisance prevention	Regulating	Disturbance moderation	8,858,570.66
2.4	Reduce flow energy	Regulating	Regulation of water flows	16,631,328.64
2.5	Slowing down the flow	Regulating	Erosion Prevention	7,734,190.85
2.6	Retention time control	Regulating	Nutrients Cycling	5,081,959.62
2.7	Pest or disease control	Regulating	Biological Control	2,812,433.10
2.8	Breeding ground	Habitat	Nursery Service	3,818,144.84
2.9	Genetic materials and resources	Habitat	Genetic Diversity	3,465,107.28
2.10	Education and research	Cultural	Inspiration	2,076,691.08
			Sub Total BENEFIT TRANSFER METHOD	**52,480,949.53**
3.	**INDIRECT VALUE – SURVEY**			
3.1	Willingness to pay-Conservation efforts ILBM	Regulating/ Cultural	CVM - Contingent Valuation Method	241,163,468.31
3.2	vents - Recreational in lake	Provisional/ Cultural	TCM - Travel Cost Method	529,112,235.92
3.3	Aesthetics - Lake front house price	Provisional	Hedonic Pricing Model	547,224,561.03
			Sub Total INDIRECT VALUE – SURVEY	**1,317,500,265.26**
			TOTAL ESTIMATION – 31 October 2015	**1,381,296,965.96**

Source: Perbadanan Putrajaya Report to UNESCO Office Jakarta (2015)

With the economic value of Putrajaya Lake and Wetlands revealed, environmental investment decisions will be well-informed and justified. The results of the research show the value of the ecosystem services of Putrajaya Lake, and most importantly, the willingness of the local population, tourists, visitors and other stakeholders to pay for ecosystem services. This would therefore help the authorities to justify its current RM 7-9 million (USD 1.6-2 million) yearly expenditure for repair works, maintenance, implementing management measures and monitoring or sampling exercise. Dissemination of information to public and relevant authorities, including political leaders, would be the key to good lake investment decisions. (Perbadanan Putrajaya, 2015)

The results had been disseminated during an international seminar in January 2016 in Malaysia, where the participants agreed that economic valuation of ecosystem services is needed in an integrated management approach.

As the constructed Putrajaya Lake and Wetlands is developing over time into a more natural setting, and enhancing its own ecosystem services, many aspects of its ecosystem services need to be assessed in terms of economic values. As a way forward, lake managers will need to work together towards understanding better the various types of ecosystem services and strengthen network and cooperation among lakes.

9.5.2 Davao City, the Philippines

According to UNESCO-IHP (2017), major issues identified in Davao city are:

- Soil erosion.
- Heavy siltation in rivers and Davao Gulf.
- Massive expansion of banana plantations.
- Talomo and Lipadas basins have poor health ratings with non-point sources of pollution.
- Unregulated groundwater use.

Ecohydrological (EH) connectivity in multiple catchments principles and solutions are used to conserve groundwater, protect surface water and contain risks in a globalizing city, Davao City. The ecohydrological principles are:

- Conserve ecohydrological processes in natural ecosystem.
- Enhance ecohydrological processes in novel ecosystem.
- Apply complementary ecohydrological processes in high impacted system. (UNESCO IHP, 2017)

UNESCO Office Jakarta, with financial assistance from Malaysia Funds-in-Trust, supported a demonstration site activity "Enhancing Resilience to Disasters of Urban Water Systems of Mindanao" to demonstrate the resilience of the urban water systems of Davao City by adopting a strategy that considers vulnerability and community resilience in the context of climate change. The activities are:

- Assessing the state of the urban water systems in Davao City, looking into the vulnerability of the people and water supply system (WSS) infrastructure;
- Strengthening integrated planning and coordination to enhance resilience in the management of the water systems; and
- Raising awareness on climate change adaptation among stakeholders by demonstrating resilience.

Further to this, an emerging project of "Rehabilitation of Balagunan Watershed to restore biodiversity and flood control in Carmen, Davao del Norte" is proposed by Davao River Basin (UNESCO-IHP, 2015).

9.5.3 Griffith-Murray-Darling Basin, Australia

According to UNESCO IHP (2017), major issues identified in the River basin include:

- Blue-green algal blooms.
- Risks of salinization.
- Loss of wetlands.

- Water over allocation and overuse.
- Floods were reduced by a factor of 3 (droughts).

The hydrological processes at catchment scale were quantified and impacts were mapped. A 3D hydro-stratigraphy model has been developed for the Murray Basin in southeastern Australia. The model can be viewed as an interactive PDF and has nine layers, which represent the aquifers and aquitards in the Murray Basin (Australian IHP National Report, 2016). The latest results reported are (UNESCO IHP, 2017):

- Improved understanding of social and economic impacts of change.
- Facilitated deliberation on complex issues, shifting individuals from interest based positions.
- Established protocols which built trust and transparency.
- Increased interest by stakeholders in decision-making for use of environmental water
- Improved relationship with indigenous groups and exploration of meaning of cultural water.

9.5.4 Western Sydney, Australia

According to UNESCO IHP (2017), major issues identified for Western Sydney are:

- Growing population.
- Land use change due to peri-urban activities.
- Run-off of pesticides and fertilizers from agricultural fields.
- Loss of riparian vegetation.
- Droughts.

Ecohydrology principles and solutions are used for developing solutions for environmental-friendly water management in peri-urban landscapes. The hydrological processes at catchment scale were quantified and impacts were mapped using ecological engineering approach. The ecohydrology engineering solutions include (UNESCO IHP, 2017):

- Water reuse and conservation using rainwater harvesting system in urban and peri- urban.
- Estimation of water allocation, stream flows, stormwater runoff through the hydrological model.
- The pollution removal performance of stormwater bioretention units built to protect river health.

The results are (UNESCO IHP, 2017):

- Nine key variables of river water quality that define river health have been identified using multivariate analysis variables and data collected over 30 years. A framework has been developed for assessing river health in peri-urban landscapes.
- Defining concept of river health from a range of perspectives.
- A simple model has been developed to predict river health with minimum number of measurements.

9.5.5 Metropolitan Beijing, China

According to UNESCO-IHP (2017), major issues identified for Metropolitan Beijing are:

- Heavy pollution from upstream Guishi River due to local fishery industry.
- Large demand in water supply from urban areas.
- Loss of natural wetlands and loss of rare species (10 rare species of water flows in 2010 comparing to 100, 30 years ago).

The suburbs of metropolitan Beijing with a key water ecosystem protection function experiences period of drought annually. A UNESCO-IHP Ecohydrology Programme Demonstration Project of "Management of regional water resources linking with managing of wetland biodiversity in the suburban area of metropolitan Beijing, China" has been presented as operational project (UNESCO-IHP, 2011).

In this demo project, researchers will develop a regionally spatial and temporal distributed EH model integrated water cycle process model and wetland vegetation response model that will simulate the regional environmental change of the past 30 years under various impacts of climate, agricultural, and ecology. The objective of the research is to reveal the process and mechanism of regional hydrological changes. The demo topic is an interdisciplinary showing for hydrology and ecology, and integration with modern information technology. It will enrich and perfect the EH theory. It is of great significance to establish a regional sustainable development pattern for balance of regional development and protection of aquatic natural resources with scientific water resources management.

9.5.6 Sanjiang Plain, China

According to UNESCO-IHP (2017), major issues identified for Sanjiang Plain, China are:

- Decrease of the shallow groundwater depth in the buffer zone.
- Decrease of Woyalan River's water level in the core zone.
- Loss of natural wetlands.
- Irrigation expansion.

Marsh wetland degradation has occurred in Sanjiang Plain. The area of the wetlands has been reduced by 80% from its original size since the 1950s due to multiple pressures, most notably drainage to reclaim land for farming (ADB, 2015). On this, the "linkage of wetland ecology and hydrology with the support of information techniques for assessing the degraded inland fresh water wetland habitat in Sanjiang Plain, Northeast China" has been listed as UNESCO- IHP Ecohydrology Programme evolving demonstration project (UNESCO-IHP, 2011).

The project's main goal was to improve management of natural resources in order to protect globally significant species and sustain economic development. The purpose (outcome) of the project was to achieve an integrated conservation and development model to protect the natural resources (biodiversity, water, forests) of the Sanjiang Plain wetlands and their watersheds from continued threats while improving the well-being of local communities.

The People's Republic of China has further implemented a $55.55 million Sanjiang Plain Wetlands Protection Project (supported by ADB, GEF and own funding) which was evaluated successful by ADB as it "increased and improved upland forest cover, restored degraded wetlands, improved wetland hydrology, increased incomes of affected households through alternative livelihoods, undertook wetland conservation education, and established wetland management capacity". (see ADB, 2015)

A number of lessons can be drawn from the project. Strong leadership and ownership, as evidenced through the commitment of the institutional stakeholders and project management office (PMO), undoubtedly contributed to the project's overall success. The survey and focus group discussions with affected people during this evaluation clearly demonstrated that the project's pioneering and successful provision of alternative livelihoods through noncash compensation or in-kind support can work in wetland restoration projects. Projects aimed at achieving ecological and biodiversity gains face significant monitoring challenges that should not be underestimated. Clear communication and understanding on financing arrangements is essential during the design of complex co-financed projects to avoid delays in implementation.

10. The Role of Regional Water-related Centres UNESCO Water Related Centre in Asia and the Pacific

10.1 Asia-Pacific Centre for Ecohydrology, Cibinong, Indonesia

Asia-Pacific Centre for Ecohydrology (APCE), a UNESCO Category 2 Centre, has contributed to a number of programme, projects, activities, and demonstration sites that promote ecohydrology approaches for enhanced recognition of ecosystem services in IWRM, either supported by UNESCO Office Jakarta or own initiatives. The activities supported by UNESCO Office Jakarta are ecohydrology demonstration activities in Saguling reservoir and Ex-Mega Rice Project in Central Kalimantan, as follow:

10.1.1 Saguling Reservoir, Citarum River Basin, Indonesia

"Improvements of Water Quality and Quantity using Ecohydrological Approach and Local Community-based Participation"

This demonstration site has contributed towards promoting ecohydrology approaches to restore the river ecosystem and subsequently aquatic and terrestrial ecosystem. The application of ecohydrology approach by increasing water retention at the catchment level through land management and controlling erosion rate using intercropping planting techniques, can prove to be a useful tool to regulate water circulation and eroded soil transportation in the catchment which will, consequently, increase the quantity of water availability, reduce the risk of floods and drought, reduce the rate of soil erosion and sedimentation. (APCE, 2016a)

Citarum River Basin and Saguling Reservoir are recognized for its strategic function at the national scale (Presidential Decision of the Republic of Indonesia No.12/2012). However, the river basin has been experiencing environmental degradation notably water pollution and sedimentation, leading to further issues due to its impacts on aquatic ecosystem, terrestrial ecosystem, as well as socio-economic impacts. (APCE, 2016a)

An ecohydrology demonstration site was established in the Saguling region, specifically Cibitung River catchment (35 km^2) as one of the tributaries in upper Citarum River Basin, aimed at demonstrating and evaluating the application of ecohydrology as well as phytotechnology in integrated river catchment management to solve the above issues. The project took place in 2015-2016, carried out by UNESCO-APCE and Research Centre for Limnology-LIPI in collaboration with other stakeholders including PT. Indonesia Power Saguling Generation Unit/UP Saguling and universities. (APCE, 2016a).

The activities included in this project are shown in Table 2:

Table 2: Activities in ecohydrology demonstration site in the Saguling region

Activities	Details
Monitoring water quality and quantity aspect	• The activity is installation of water monitoring instrument with a real time, online-based system recording data at upper area, middle area and downstream area of the river catchment • The obtained data and information includes: the site name, date-time, water temperature (oC), turbidity (NTU), conductivity (uS/cm), water level (mm), wind speed (m/s), wind direction (degree), air temperature (C), humidity (%), barometric pressure (hPa), rainfall depth (mm), level battery (V), date-time of wind speed maximum, wind speed maximum (m/s).
Ecohydrological modelling system: preliminary application of rainfall- sediment-runoff model In the upper Citarum river basin	• The study confirmed that application of the rainfall-sediment- runoff model could accurately simulate streamflow discharges, spatial-temporal measurements of the dynamic sources of soil erosion and deposition, and sediment yield amount. • It will be used as a core tool to assist in the design of control strategies for: (1) improvements of water quality and availability, and (2) trapping and controlling sediment supply within the potential priority locations or sub-catchments.
Phytotechnology application for water quality improvement	• The activity is the construction of 36 phytoremediation ponds at the size of 2m x 5m x 0.5m for water rehabilitation polluted by wastewater, before channeling back to the reservoir/river water system • Wastewater sources are domestic waste, paddy field waste, the sago industry, and river flows within the demonstration site area. • The implemented concept is aquaculture in the ponds: floating plants to remediate water by taking up nutrients in plant biomass and fish to enrich nutrients and feed on the plant biomass • Floating plants include Lemna perpusilla Torr, Landoltia punctata, Salvinia sp., Pistia stratiotes, and Eichhornia crassipes, for removal or degradation of contaminants. • Fish include cat fish (Clarias sp.) and Nile Tilapi(Oreochromus sp.). • Measurement results show that all floating plants reduced water turbidity as measured on day 1 (30 March 2016) until day 64 (1 June 2016) • Socio-economic aspect: The selection of plants considered usability of the plants as alternative feeds for fishery, to showcase socio-economic benefit. This is aimed at encouraging further community-based phytotechnology application elsewhere
Environmental sanitation and erosion control aspects of ecohydrology demonstration site	There are two activities: • the development of Detailed Engineering Designs (DEDs) as an alternative design of the sewerage system in order to improve environmental sanitation, for the selected residential area located close to the phytotechnology ponds; • the development of concept and DEDs for controlling soil erosion rate using ecohydrology approach with the use of vegetation to minimize anthropological structure. The concepts are: (i) terracing, (ii) mulching, and (iii) intercropping planting techniques.
Integrating socio-economic-cultural aspect	• The activity is carrying out survey to 42 respondents from eight sub-villages to understand their existing habit, perception, and response to the existing of new developed ecohydrology demo site • It was noted that existing habits include disposal of waste into the river and thus the project recommends improvement of sanitation facilities • The willingness of the local community to participate in environmental management was relatively strong, including involvement in ecohydrology demonstration site activities.

Source: APCE report for UNESCO Office Jakarta (2016a)

(a) **(b)**

Figure 24a: Phytotechnology ponds with aquaculture approach.
Figure 24b: Detail Engineering Designs for communal sanitation system and wastewater management.
Photo credit: APCE (2016a)

The project results showed that the application of ecohydrology and phytotechnology measures in the Saguling Region has been successful, considering its high ownership by the local communities and authorities. This is due to the cost effective and comprehensive measures applied to address environmental concerns (water quantity and quality issues), which considered the following principles: hydrological, ecological, ecotechnological, and cultural. (APCE, 2016a)

10.1.2 Ex-Mega Rice Project in Central Kalimantan, Indonesia

"Study on the Implementation of Ecohydrology Approach and Avoided Deforestation in Peatland Rewetting and Conservation in Ex-Mega Rice Project"

This demonstration site has contributed towards research on sustainable peatland management using ecohydrology approach, by identifying hydrologic regimes of the peatland in order to fully understand soil character, assess plant suitability, and recommend approaches and actions to ensure peatland management that is sustainable. (APCE, 2016b)

Peat swamp forest is a unique and fragile ecosystem, home to specific flora and fauna that play important roles in maintaining healthy natural conditions, with high economic value. Understanding the ecohydrology of peatland is important for properly managing peatland resources. On this end, an ecohydrology demonstration site was established at peatland area of Pangkoh district, Kanamit Barat village, Central Kalimantan, to develop model ecohydrology approach in managing peatland hydrology suited to the specific peatland typologies, in an ex-mega rice project located on food crops areas and oil palm plantation areas. In doing that, the project covers research to: 1) understand ecohydrology characteristics of the different peatland typologies, 2) identify hydrologic regimes of the peatland, 3) identify vegetation patterns in the peat land forests to understand the roles of hydrologic regimes regulating the biota regimes, and 4) identify peat water quality and further treatment needed. This collaborative research project was implemented during 2015-2016 by APCE UNESCO Category II water centre, Research Centre for Limnology-LIPI, University of Palangkaraya, University of Lambung Mangkurat, Balai Penelitian Rawa of the Ministry of Agriculture, and Balai Rawa of the Ministry of Public Work and Housing. The research area of Pangkoh district has a sulphidic (pyritic) material underlying the peat layer. (APCE, 2016b)

The research activities included in this project are:

Table 3: Activities in ecohydrology demonstration site in the Pangkoh District

Research Items	Main Findings
1. Hydrophysics aspects	• The research has resulted in important findings in relation to the implementation of ecohydrological approaches toward sustainable management of peatlands. • The results show that hydro-physical properties of peat materials varied with different land uses and have consequently led to different degrees of peat decomposition.
2. Water management	• The hydro-topography of the study areas has changed based on the changes of land elevation and the fluctuations of surface water elevation. There were several conflicting interests in managing the water level in the area caused by different land use. • Surface water has small influence to the fluctuation of the groundwater. • The water system was already intervened for different purposes. The tidal potential was not used due to over drainage and lowering the water level which also as an impact from climate change.
3. Agricultural aspect	• The objective is to determine suitability of different types of plant commodity in the research area (Kanamit Barat and Kanamit Jaya village). This is done through surveys to 20 farmers respondents,and by soil and planting samping for analysing soil character, plant commodity, indigenous knowledge, and agricultural technology. The research area was previously cultivated for agricultural land (paddy/rice), pulses, rubber and oil palm plantations. • Data analysis show that currently industrial crops offer higher profits than food crops. • It was found that the biggest contributor to the welfare at household level is rubber plantation. • The peatlands in the research area are less suitable for plantation crops due to its pH, very low nutrient availability and the risk of inundation.
4. Land use change and carbon dynamic aspect	• The condition of peatlands in the research area (Pangkoh) is already in a degraded state as indicated by the decrease in peat thickness. • Biogeochemical properties and environmental conditions, including hydrological condition (water table) and land use change, largely affect the carbon loss via water (DOC) and emission from peatland.
5. Water and environmental dynamic aspect	• Water sampling was conducted at five stations located in Kanamit Barat village, consisting of two stations on the canal, one station in rei (a small stream that cuts the road), and two stations in the community wells. • Water quality results as follow: Canal 1, Canal 2 and Rei were classified as peat water, while Well 1 and Well 2 were not classified as peat water and are thus suitable for consumption by the public as water for drinking and daily needs but must go through treatment processing and should not be consumed directly.

Source: APCE report to UNESCO Office Jakarta (2016b)

Figure 25: Water condition in the research area
Photo credit: APCE (2016b)

Based on the above findings, the study recommended that ecohydrological approach for sustainable peatland management should consider the following (APCE, 2016b):

- Conservation or utilization of a peat dome that requires the management of each dome as a single hydrological unit, as the water table in each deposit is contiguous. Contrasting uses within a single unit are likely to lead to conflicts, which, while manageable in the short term, would be unsustainable in the long term. Hydrological change in one part of the unit will ultimately affect the rest of the unit.
- Protection and rehabilitation of peatland hydrological system have important roles for managing forest, plants and carbon sinks in sustainable manner and to maintain the potential economic values in the long term.
- Keeping water tables as high as possible is the basic principle for peatland management. This way, control structures should be introduced to canals in order to enable effective control of water level fluctuations from seasonal patterns. Phytotechnology remediation could be introduced using locally available plants.
- Community based approach is required to plan, operate and maintain water control structures such as canal blockings that is not in practice yet. Some financial supports to local farmers would be necessary.
- In order to maintain and rehabilitate hydrological conditions, degraded land with low conservation value or low potential for agriculture should be retained and vegetation cover should be improved.
- Fibre plantations which provides livelihood opportunities for local communities should be encouraged.

10.2 International Centre for Water Hazard and Risk Management (ICHARM), Tsukuba, Japan

ICHARM (International Centre for Water Hazard and Risk Management under the auspices of UNESCO) has developed a next-generation river discharge measurement system that ensures precisions, highly reliable measurements with automated measurement for better understanding on river systems. The measurement method uses fixed current meters such as non-contact current meters (radio current meters) combined with an acoustic Doppler current profiler (ADCP) for accuracy control. Pakistan is one of the countries benefitting from the technical expertise of ICHARM on river discharge measurement, with UNESCO's support (with Japanese financial assistance), where a hands-on training on discharge measurements reflecting boat navigational skills and equipment understanding had been delivered by ICHARM for engineers. (UNESCO, 2017b)

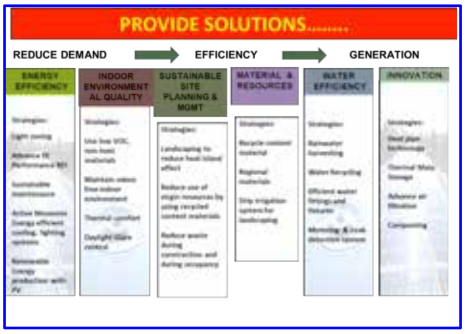
The equipment includes a Teledyne RDI RiverRay, a RiverPro and the tethered boats as well as a Ryukan (non-contact current meter) and will allow precision measurements on river discharges and river profiling in high and low flows for better understanding on the river systems and ultimately their better modeling within the flood forecasting model Indus-IFAS (Integrated Flood Analysis System) developed by ICHARM (International Centre for Water Hazard and Risk Management under the auspices of UNESCO), Tsukuba, Japan.

10.3 Humid Tropics Centre Kuala Lumpur (HTCKL)

HTCKL (Humid Tropics Centre Kuala Lumpur) a category 2 water centre for Hydrology and Water Resources under the auspices of UNESCO) has successfully developed software Decision Support System (DSS) for Integrated Stormwater Management Ecohydrology in collaboration with a team of lecturers and researchers from University of Tenaga National, Malaysia (UNITEN).

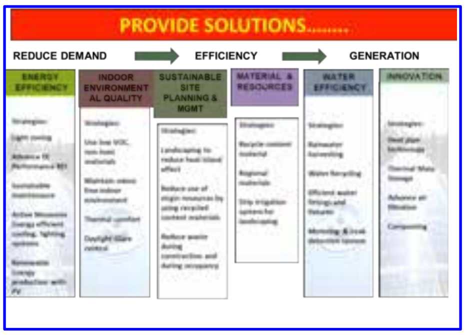
The MSMA Integrated Stormwater Management Ecohydrology Design Aid and Database System is computer design support to optimise the performance of storm water BMPs as it is strongly dependent on specific site criteria including type of land use, hydrological data and maintenance frequency. The objective is to assist engineers and local authorities to select the most appropriate strategy for storm water BMPs trapping stormwater pollutants in urban area during construction and post-construction. The computer design support system can be used in Asia and the Pacific region. The rationale behind the project is to provide solutions as shown in Figure 26.

(a)



(b)

(c)



(d)

Figure 26: Solutions needed in urban SME (after HTCKL, UNITEN, 2015)

The modules framework is shown in Figure 27.

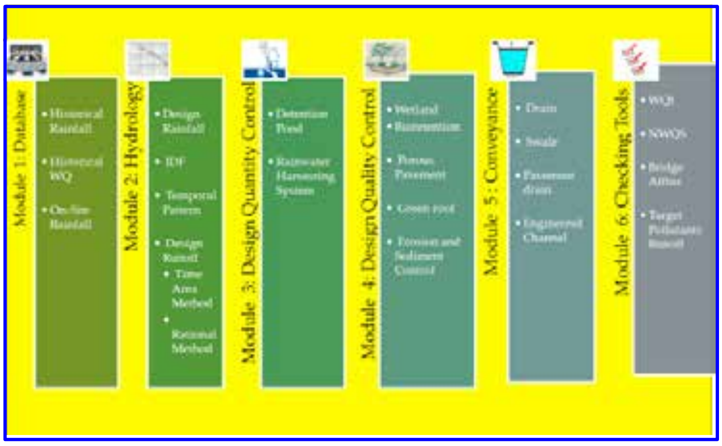


Figure 27: The modules framework (after HTCKL, UNITEN, 2015)

The Stormwater Management Ecohydrology Design Aid and Database System consist of: (a) Design Information; (b) Model Input Data; (c) Catchment Characteristics; and (d) Life Cycle Costs. These 4 criteria are broken down into 2 sub parts:

a) Structural components

- Constructed Wetland,
- Bio Retention,
- Rainwater Harvesting,
- Green Roof, etc.

b) Non-structural components

- Planning Policy,
- Community Awareness,
- Monitoring, etc.

The way forward for commercialization strategy and HTCKL as regional SME referral is shown in Figure 28.

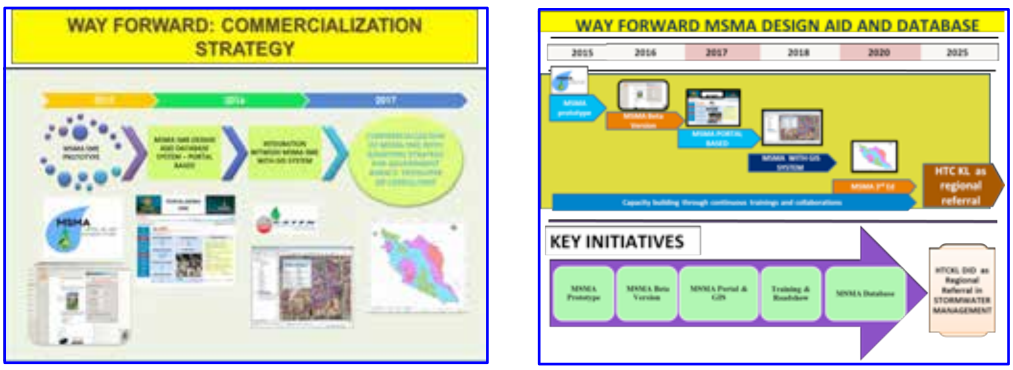


Figure 28: The way forward for SME Design Aid and Database System (after HTCKL, UNITEN, 2015)

11. Lessons Learnt and Remarks

- Freshwater ecosystems provide many economically valuable commodities and services to society. These services include flood control, transportation, recreation, purification of human and industrial wastes, habitat for plants and animals, and production of fish and other foods and marketable goods. (Baron, J.S. et al., 2003). These ecosystem benefits are costly and often impossible to replace when aquatic systems are degraded.
- Efforts need to be taken to develop 'soft engineering' technologies techniques to complement 'hard engineering' solutions. The management approach has to go beyond protection and restoration to recognize the carrying capacity of ecosystems as find a ways of improving and transferring solution across a variety of environment.
- Education about water issues will have has to occur at all levels to equip people with the knowledge, skills and values to play a role in protecting the resources.
- Vital information about the health and needs of a freshwater system could be obtained through Freshwater Ecology study, the study of the interrelationships between freshwater organisms and their natural and cultural environments.
- IWRM approaches, in the which comprise management of water resources, disasters and environmental issues, is are needed in the managing competing uses across interests and sectors and in coming up with by building compromises through stakeholders participation. Benefits of IWRM to the sectors include agriculture, water supply and wastewater, mining and industry, environment, fisheries, tourism, energy, transport, etc.
- An IRBM plan for a particular river should be formulated and treated as the overall macro water resources management master plan for the river basin, involving all relevant stakeholders.
- Ecohydrology should be used in creating a scientific basis for a socially acceptable, cost-effective and systemic approach to the sustainable management of freshwater resources.

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Appendix A

Proposed Integrated River Basin Management Plans (including Detailed Design of Identified Physical Projects) (after Roseli, 2016)

1. Objectives of IRBM Plan

- To promote a dynamic & multi-sectorial approach to water resources management.
- To plan for the sustainable management of water resources.
- To mitigate the flood and draught problems.
- To identify and develop appropriate institutional, legal and financial mechanisms to ensure that the water policy and its implementation are a catalyst for a sustainablesocial progress and economic growth.

2. General Contents of IRBM Plan

- A statement of the objectives of the plan;
- A reference to other policies and plans that impact on the river resources and the water environment;
- Identification of the water resources of the river basin;
- The status of the quantity and quality of the water resources including current condition and development trends;
- The activities that significantly influence the quantity and quality of the water resources and assess the impacts;
- The water quality objectives for the water bodies;
- Strategies and measures for the protection, conservation, development and use of the water resources and for maintaining or improving the quantity and quality of water and the water environment;
- Indicators for the achievement of the objectives and the implementation of the measures; and
- Identification of areas that require special protection and of areas for extraction of sand and other rock materials.

3. Detail Contents of IRBM Plan

3.1 Part 1

1. **Introduction**

    - General Statement about Water Problems
    - The River Basin
    - Issues in Water Resources Management
    - Objectives
    - Goals

2. **Status and Assessment of Water Availability and Usage**
3. **Existing Policies and Plans**
    - Policies
    - Targets
4. **River Management Policies, Strategies and Measures**
    - Policies
    - Ensure sufficient water
    - Ensure clean water
    - Reduce floods risks
    - Conserve and develop the river ecology, biodiversity and ecosystem

3.2 Part 2

1. **Engineering Aspects**
    - Water Resources
    - Hydrology
    - River Hydraulic
    - Irrigation
    - Hydropower
2. **Scientific Aspects**
    - Terrestrial and Aquatic Biodiversity
    - Fish and Fisheries
    - Environmental Planning
    - Geology and Soil Erosion
    - Agriculture
    - River Pollution
3. **Watershed Planning and Social Impact**
    - Landuse
    - Tourism
    - Landscape
    - Economic and Financial
    - Navigation
4. **Institutional and Legal Administrative**
    - Institution
    - Legislation

3.3 Part 3

1. **Catchment Management Plan**
   - Forest Management
   - Agriculture Management Plan
   - Dams Management
   - River Basin Management Units (upstream, middle, downstream)
   - Environmental Sensitive Area
   - Flood Mitigation Plan
   - Riverbank Erosion Prevention Plan
   - River Mouth Siltation Prevention Plan

2. **Water Resources Management Plan**
   - Water Conservation
   - Water Demand
   - Water Resources Facilities
   - Environmental Maintenance Flow
   - Water Reuse and Recycling
   - Ground water

3. **Environmental Management Plan**
   - Water Quality Monitoring Plan
   - Water Quality Management Plan
   - Sewerage Master Plan
   - Urban Stormwater Management Plan
   - Erosion and Sedimentation Control Plan
   - Aquatic Biodiversity Master Plan
   - Wetland Management Plan
   - Environmental Monitoring Plan
   - Mangrove Management Plan

4. **River Corridor Management Plan**
   - Inland Navigation
   - River sand mining
   - Floodplain Zoning Plan
   - River Riparian Zone Management Plan
   - Recreation and Tourism Plan
   - Beautification and Land

5. **Climate Change**
   - Effects on Water Resources
   - Effects on Rainfall Pattern and Magnitude

6. **River Basin Information System**

7. **Implementation Road Map**
   - Short Term
   - Medium Term
   - Long Term

Topic 2

Natural River Ecology, Ecosystems and Hydraulics

Mobilizing Science for Healthy Ecosystems

Bogor, West Java
Indonesia

Topic 2

Natural River Ecology, Ecosystems and Hydraulics

Summary

For effective management of healthy riverine ecosystems, it is important to understand the varying controls and their scales of influence, as well as how they affect ecosystem response variables such as biodiversity, productivity and biogeochemical cycles in rivers and streams.

1. Introduction

1.1 If rivers were straightened, to improve their flows over time, the channel can end up as large drains and even get clogged up with weeds and rubbish. When rivers are "redesigned" back to their meandering ways, with pools, runs and cascades, the results would be the return of fish without the need for re-stocking. Riverbanks which have been concreted will result in the loss of natural river morphology. It also can trigger the deepening of the riverbed upstream. The concrete surface eliminates all river habitats for all kinds of fish and aquatic life. All protection and breeding (nesting) are eliminated because there is no place to stick the egg. Plants are also eliminated. Therefore, contribution from plants and aquatic contribution to improve water quality does not exist. In river works the focus should be on safe guard and enhancement of surface freshwater ecosystem especially for watershed river basin management. (Roseli, et al., 2017)

1.2 Understanding the nature and characteristics of the river is very important as a basis of every planning or designing programs that involve river. Various human activities at the upstream and middle reaches of the rivers resulted in the increasing drainage of sewage disposal and the pollutant substances. There is a need to give appropriate and more attention and awareness on the degradation of water quality in the upstream/middle reaches of river catchment and the increase of floods events and magnitude.

2. River Ecology, Ecosystems and Zoning of Rivers

2.1 The ecology of the river refers to the relationships that living organisms have with each other and with their environment – the ecosystem. River ecosystems have flowing water that is mostly unidirectional, a state of continuous physical change and many different and changing microhabitats. Ecosystems provide a variety of goods and services upon which people depend; the principles of ecosystem management suggest that rather than managing individual species, natural resources should be managed at the level of the ecosystem itself.

2.2 All rivers, regardless of their type, have the same stages of structural changes from source to delta. The profile of every river can be divided into three zones: source zone, transfer zone and deposition zone. Zoning of rivers into water catchment and development zones and still preserving its natural ecosystem can be divided into upstream reach (nature zone and nature use zone), middle reach (nature use zone and development zone), and downstream/river mouth (development zone).

2.3 The sequencing of pools and riffles within a river section, and the existence of various habitats illustrates the variety of life adapted to both fast and slow currents and serves as a precondition for a well-functioning river ecosystem.

2.4 The level of groundwater depends on the level of water in the riverbed. In dry periods or during periods of no rain, surrounding areas drain into the river bed and groundwater runs towards it. During flooding, the groundwater direction may reverse.

2.5 Floodplain provides temporary storage for floodwaters, storage for sediment from watershed to settle before flowing into the river, space for channel to migrate over time, etc.

2.6 Riparian zones are important in ecology, environmental management, and civil engineering because of their role in soil conservation, their habitat biodiversity, and the influence they have on fauna and aquatic ecosystems, including grasslands, woodlands, wetlands, or even non-vegetative areas. These zones are important natural bio-filters, protecting aquatic environments from excessive sedimentation, polluted surface runoff and erosion, supply shelter and food for many aquatic animals and shade that limits stream temperature change. Riparian zones are instrumental in water quality improvement for both surface runoff and water flowing into streams through subsurface or groundwater flow, can play a role in lowering nitrate contamination in surface runoff, such as manure and other fertilizers from agricultural fields that would otherwise damage ecosystems and human health The riparian zones also provide wildlife habitat, increased biodiversity, and wildlife corridors, enabling aquatic and riparian organisms to move along river systems avoiding isolated communities and many other benefits.

3. River Hydraulics

3.1 In any sustainable water resources quantity and quality obligation, management, enhancement, maintaining channel ecosystem and the natural hydraulics of flow is important. A natural river ecosystem usually comprise of main channel and floodplain. The recommended typical river section to be used in planning, design and construction should be closer to the shape of a natural river with storage function and storage area. It should not be changed into a "U' shape or trapezoidal.

3.2 In determining the designed discharge, the resistance equations such as Manning, Chezy, and Darcy-Weisbach can be used effectively for the main channel. Many natural rivers have floodplains beside the main river channel and in times of flood these floodplains may act as a store for water. In overbank flow, the main river channel flow is usually affected by the floodplains and the overall conveyance capacity is reduced. Besides resistance there is also an area of storage to be included in the design of discharge and water level for flows above bankfull in the transition zone and overbank flow. One of the methods that addressed this issue, an improvement to the traditional methods is in using Ackers' coherence equation. It is recommended that a higher design water level should be used than those obtained from using Manning' equation and software for the same overbank flow discharge unless in the calculations the cross-section used include the storage function of the natural river ecosystem.

3.3 As a flood wave passes through a river reach, the peak of the outflow hydrograph is usually attenuated and delayed due to channel resistance and storage capacity. There will be a decrease in the peak discharge and deformation of the hydrograph once the flow exceeds bankfull discharge. For two-stage channel i.e. river with main channel and floodplains as the usual case for a natural river, the shape of the hydrograph is different for flow in the floodplains (overbank flow). The time of peak of the peak outflow is delayed further and hence more attenuation. It is recommended that to get maximum attenuation (maximum reduction of peak outflow discharges), the design water level should be in the transition zone between inbank and overbank flow).

3.4 A water balance equation can be used to describe the flow of water in and out of a system. Water balance can be referred to the ways in which an organism maintains water in dry or hot conditions. It is often discussed in reference to plants which have a variety of water retention mechanisms. A water balance can be used to help manage water supply and predict where there may be water shortages. It is also used in irrigation, runoff assessment such as through the rainfall-runoff model flood control and pollution control. In flood mitigation works involving rivers the rate of change of storage with respect to time is more important than storage alone especially if included in-lined and off-line ponds.

4. Making Rivers Rich in Nature

4.1 When designs of river projects disturb the biodiversity and natural ecosystem or have potential detrimental impacts to the ecosystem, the projects will most likely deprive human-being from sources of clean, fresh surface water. When projects implemented do not include enhancement of natural river ecosystem, biodiversity, ecology, ecohydrology such as in river restoration works, river cleaning, and improvement in water quality, river of life, stormwater management, flood mitigation and control, the output, outcome and deliverable target difficult to be met. Efforts should be directed towards designing more natural rivers that are safe and free from disaster that enhances the beauty of landscape, and that is friendly to life forms. Rivers should become a pleasure resort for human beings to enjoy, a place to relax and to come to terms with nature.

4.2 The construction and management of rivers demands there should be shallows, deep waters, a clear flow of water and a habitat for the thick and lustful growth of plants life, birds, fishes, insects and other species of life forms. Examples of rivers rich in nature in Asia and the Pacific Region:

(a) The multi-sectoral Davao River Conservation Coordinating Committee (DRCCC) was formed to help conserve the Davao River, Philippines. The City Council approved the Watershed Management Code, officially upholding an integrated approach in managing the interactions among water, land, and life forms in the eight river basins drains into the Davao Gulf. UNESCO IWRM Guidelines was localized and customized based on the actual experiences of Davao City and Davao Region through the participative engagement of all stakeholders involved in planning of the Davao Water Action Plan and drafting the resolution for the Region-wide adoption of IWRM Guidelines; furthering knowledge through research and development; furthering understanding through consultations; furthering cooperation through partnerships; furthering local capacities through capability building; sustaining implementation through enabling policies, and resolutions.

(b) The development of the Brantas Basin, Indonesia, started with a comprehensive multi-purpose project based on the concept "One River – One Plan – One Management", and includes multi-purpose dams and reservoirs which, among other things, improved flood control, irrigation, power generation, domestic and industrial water supply. A special inter-provincial and cross-sectoral institution, the Water Resources Management (WRM) Committee was established by the East Java Governor as a coordinating body to direct all aspects of water resources management (planning, implementation, supervision, control, and funding). This includes allocating water among users in the basin and conflict prevention. Brantas River Basin Development Project (BRBDP) was also set up to implement basin-wide development run by the central government.

(c) During 2009-2012, South Korea carried out projects to clean-up four (4) major rivers including Han River, Nakdong River, Geum River and Youngsan River in an effort to develop fundamental measures to counter floods and droughts caused by abnormal climate. The rivers become a center for the coexistence of people and nature. The clean-up project is a success story in designing nature-rich rivers, while at the same time managing floods and droughts.

(d) There are many nature-rich rivers improvement works in Japan. The river works carried out involved enhancement the natural river ecosystem by considering and practicing: Even if the river was constructed to be straight, the meandering nature of the flow persists and in turn the flow channel meanders regardless of the fact that the river is straight. Due to this, shallows and deep waters are always found in rivers. In addition, the water edges of these rivers are never uniform and consist of bends. The normal-line low-water channel design which produces bends and divergence are applied to rivers fixed in concrete to make it look more like a natural river and encourages the formation of shallows and deep waters. Shallows and deep waters effectively enhance the self-cleaning action of the river by drawing air into the water, causing contaminants to form sedimentation and so on. The pebbles and soil by its water edge also encourages the activity of macro-organism.

5. Some Recommendations on Rubbish Traps

5.1 Some types of Gross pollutant trap (GPT) may be suitable to be used in some countries but may not be suitable for others. Similarly they may be suitable in some projects but may not be suitable for others. It will be suitable if the trapping is intended to be limited to only gross pollutants and solid waste. However, it is not suitable when the rubbish includes sludge, oil & grease, chemical waste, coloring materials such as dye, etc. It will also not be suitable when leachate are produced and discharged to the river. River will become much dirtier, and form of life in the river will be affected. The GPTs installed could be very costly and operation and maintenance works could be difficult to carry out. The GPT will therefore need modification or different types of GPT should be used. Some simple, cost effective GPT which are easy to install and can make use of locally available materials are recommended as follows:

(a) The Gross Pollutant Trap Offline with four separated zone: rubbish trap, oil & grease trap, filtration and eco-logical blocks to trap solid waste, sediment, oil & grease separately offline in a GPT system for drains and small stream.

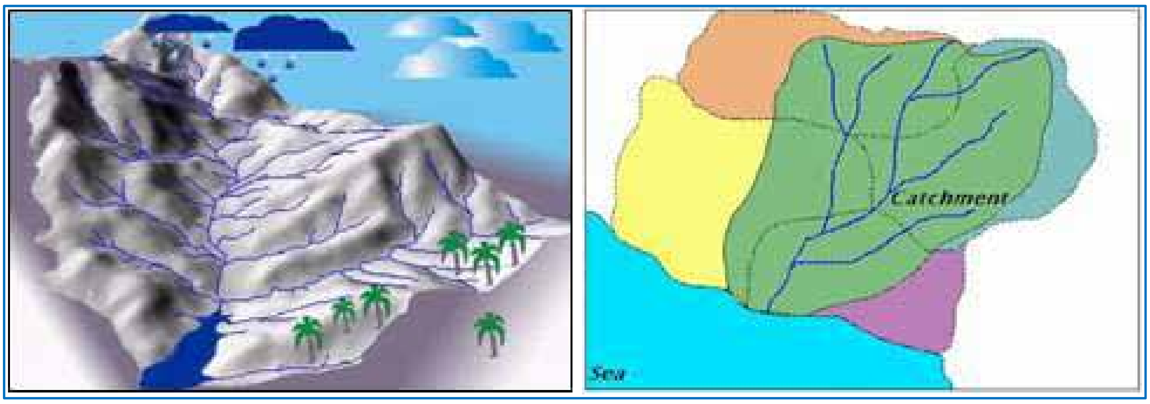
(b) The Gross Pollutant Trap to treat wastewater for wet market disposal. The treatment system is divided into three zones: rubbish trap, filtration and eco-biological blocks.

(c) The interlocking Modular Floating Rubbish Trapper (MFRT) to trap floating rubbish in drainage system, stream and middle size rivers. The MFRT can trap effectively floating rubbish such as solid waste, oil & grease, plastic bottles, plastic & polystyrene food container, floating plant and undergrowth, leachate, etc. An offline collector chamber can also be provided. It can also be constructed offline, at the end of drain, at drain sump, etc. The rubbish can also be collected offline using mechanical collector system. Another MFRT is called anti-backflow rubbish trapper (ART) suitable to be used at the end of small drain before joining monsoon drain, stream or river. The modular tube can also be used as drain.

1. Introduction

Rivers sustain more than fish, they sustain life. If we listen carefully, we can hear our rivers crying. Yes, our rivers are in dire need of help. Rivers which once served as highways and source of water for drinking, cleaning and bathing have become the dumping place of agricultural, industrial and household waste. In short, we are turning our rivers into mega drains (the Star, 2009). If rivers were straightened, presumably to improve their flows over time, the channel can ended up as large drains and even got clogged up with weeds and rubbish. When rivers were redesigned back to their meandering ways, with pools, runs and cascades, the magical results was that, not only we have beautiful rivers back, but the fishes can re-appeared even without re-stocking. This drives home the point that if we leave nature to its own course it will heal itself.

River means any river, stream, creek or other natural water course, and or any tributary, distributary or artificial deviation thereof (Section 5 of the Malaysia National Land Code, 1965 (Act 56)). River Basin means the area of land from which all surface run-off flows through a sequence of streams, rivers and possibly, lakes into the sea at a single river mouth, estuary or delta (Adapted from EU Water Framework Directive, 2000). Figures 1 (a) and (b) show the definitions of river and river basin.



(a) **(b)**

Figure 1: Definitions of river and river basin

A river can also be defined as any natural stream of water that flows in a channel with defined banks. The source of a river may be a lake, a spring, or a collection of small streams, known as headwaters. From their source, all rivers flow downhill, typically terminating in the sea/ocean as sketched in the Figure 2. Figure 3 illustrates a natural river section, floodplains, and river reserves (Roseli, et al., 2017a).

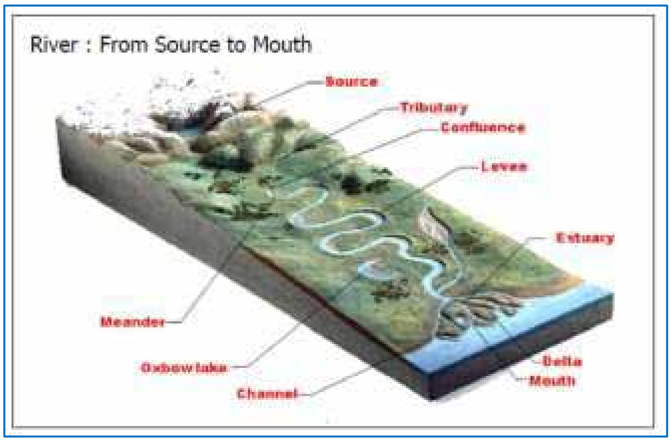


Figure 2: A typical river system (after FLSRWG, 1998)

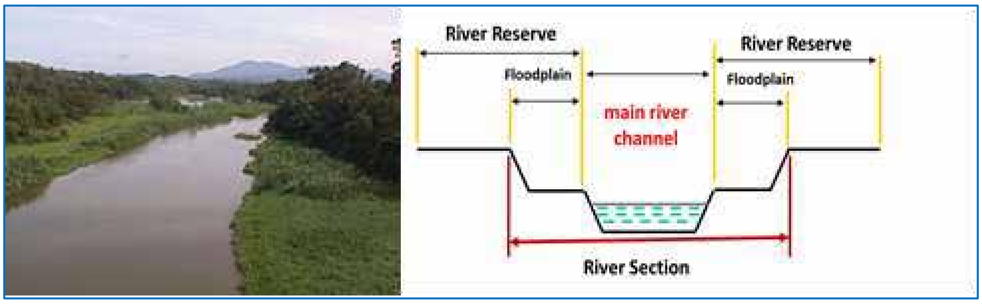


Figure 3: Natural river section, floodplains, and river reserves (after Roseli, et al., 2017a)

Riverbanks which have been concreted will results in the loss of natural river morphology. It also can trigger the deepening of the riverbed upstream. The concrete surface eliminates all river habitats for all kinds of fish and aquatic life. In addition, it changes the natural river meander with various breadth, depth and hardness into uniform canals. All protection and breeding (nesting) are eliminated because there is no place to stick the egg. Plants are also eliminated. Therefore, contribution from plants and aquatic contribution to improve water quality does not exist.

When the flow is low, the water temperature will increase when flowing through the concrete surface. The breed algae growth will again lower the oxygen level of the water. This condition is extremely unsuitable for aquatic life and fish. Usually concrete sections on the river did not have aquatic life. Such example is shown in Figure 4. This section of the river which flows in the heart of a city has been turned into a concrete drain channel completely, which disturbs biodiversity and natural ecosystem.

Figure 4: The river with a loss of morphology, biodiversity, ecology and ecosystem

In river works the focus should be on safe guard and enhancement of surface freshwater ecosystem especially for watershed river basin management. The function of river can be as follows: (1) Primary function: surface water resources management; (2) Secondary function 1: as water conveyance, storage and sediment transport (3) Secondary function 2: as natural ecosystem for socio-economic management.

2. Characteristics and Features of Natural River

The river is a dynamic system, constantly changing in form and its position. We need to have an understanding of the function of the components in river basins (such as upland, wetland, floodplain) to resolve the problems and issues relating to land - water. Understanding the nature and characteristics of the river is very important as a basis of every planning or designing programs that involve river. The river is caused by the impermeable rain water, lakes and springs that seep out of the ground. Figures 5 to 7 and Appendix A show the characteristics and features of natural rivers.

1. **Young river**. Young river is the initial stage of the catchment area of the river, begins when the water springs and streams meet to form the river. The physical characteristics of the young rivers are: waterfall; rapids and underground rivers.

2. **Waterfall**. Formed when the change in ground level occur where the flowing river turned its water level suddenly. Water will plummet to levels or periphery. There are many waterfalls along the young river.

3. **Rapids**. Formed when changes occur in bed level and water profile of the river, where the river level will change little by little in terraces in rocky area. At the bottom, a pool will be formed. Rapids have various levels of swift flowing water and will form the swirling (turbulent) water. The speed of the water in rapids is usually high.

4. **Underground river.** Most of the rainwater that falls on the mountains and hills will flow as a river. For mountain and hill built of limestone will easily get assimilated because it is of permeable type. When the river water falls and absorbed some carbon dioxide from the air, falling water turns into a kind of weak acid. This acid is capable of resulting in rock breaking and cracking and forming limestone caves. This water cannot pass through the impermeable rock but will flow following the base of the cave as underground river.

5. **Mature river**. Rivers will flow leaving the hills and mountains and is on mature stageSince the land is not very steep, the river flows quite slowly. There is more water as more tributaries connected to the river. Big amount of sand, mud and pebbles are brought together by its current.

6. **Old river**. River arriving in flat land will flow to the sea. River at the old stage will flow with great quantity of water. The currents are slow while the water muddy and sandy. When heavy rains occur can cause the area or field of flat surrounding land get flooded. During flood, the river will sometimes change the course. Diversion or meander may be cut off from the main river. These diversions will form a horseshoe- shaped lake and eventually become dry. When the flood waters recede, flat field or pasture with water will be covered with fine mud. This allows the growing of fertile grass.

7. **River mouth/estuary**. When the river flows into the sea it embodies the characteristics of attractive river mouth and it is called mouth or estuary. River water meets with sea water. Here the river leaves the sand and mud that it brought. Mud and sand left by the river form a delta.

8. **Still water**. It is calm water in a flat plain land area. The situation is calm and clear water makes it a breeding ground for aquatic life. In addition, fertile plants and vegetation grow in this area.

9. **Slow flowing river**. Exist in flat plain land area and usually close to the sea.

10. **Fast flowing river**. Usually exist in an area which is steep and at the hillsides. The steep hillsides create fast flowing current which is dangerous and silts.

11. **Highlands**. Hilly forest area: area of accumulation of rain and water resources. Supply sediment to the river system and the ecosystem.

12. **Wetlands**. Regulate movement of water in the catchment area. Role as a supplier of water, filter and wash filtering the nutrients and sediment and including recycle chemicals and organic particles.

13. **Flood plain**. Flood plain plays its role as a channel and storage of water during heavy rains and high flows. Storage is increased if the river is wider and longer. It can serve as wetlands. Reduce the rate of peak flow and the risk of flooding downstream.

14. **Construction of dams**. Construction of dams will create ponds. Clean water that comes out has redundant power, consequently eroded the river and in other parts result in deposition. Construction of the dam could damage the ecology/ecosystem of the river.

15. **Sand extraction**. Sand is an important source of development. Uncontrolled extraction causes damage to the river and the environment.

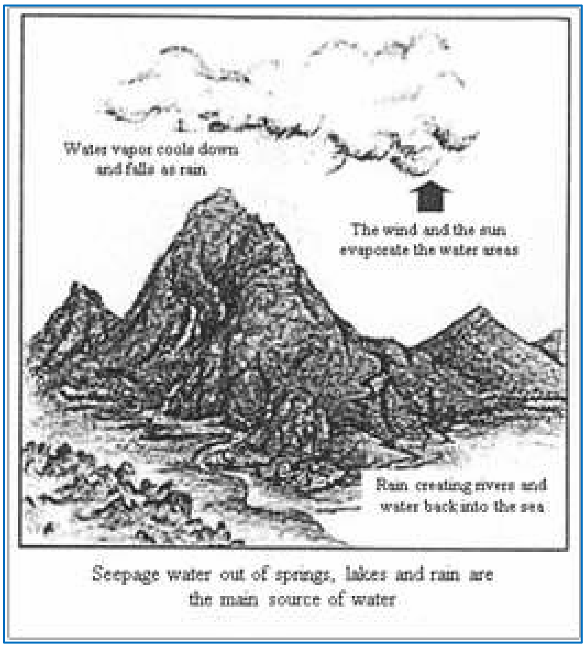


Figure 5: Understanding formation of river

Figure 6: Types of river

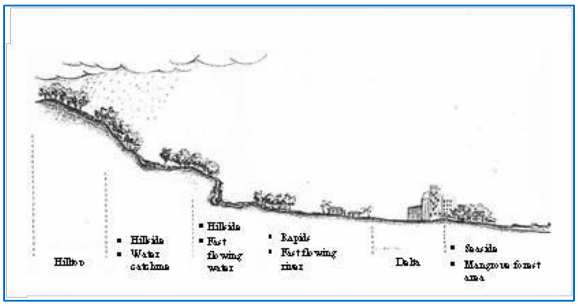


Figure 7: River profile

3. Issues and Challenges

a. Some facts about river

- Everyone lives in a river basin. Human activities usually result in negative impact to rivers. Public awareness of our impact to rivers and their environment is very critical;
- Integrated River Basin Management (IRBM) and Integrated Water Resources Management (IWRM) are closely related approaches on water resources;
- Establishment of institutions and legislation are vital for proper river basin management;
- Water demand continues to increase from industry, domestic, agriculture and hydropower;
- Economic development is closely linked to water resources/water supply.

b. Problems in present management of river basins - example in Malaysia

- Currently there are many ministries and agencies (at federal level, states, local governments) involved in water management; however the functions, roles and responsibilities are still not clear;
- Sectorial approach to problems - depending on departments or agencies involved;
- Lack of clear or given mandate;
- Lack of coordination among agencies;
- Lack of coordination with other states;
- Land and water are not managed as a whole – still based on political and administrative boundary;
- No River Basin Organization (RBO) to manage rivers;
- No clear river reserves: river reserves not gazette and riparian zones are not identified;
- Relevant laws regulating river and environment not yet established

c. Rapid development and urbanization

When natural ecosystem is not given proper attention, rapid development and urbanization can lead to flash floods (less pervious areas); increasing demand for clean water; water supply problems; pollution/degradation of water quality; erosion and sedimentation; destruction of river and coastal habitat/environment; depletion of aquatic life; and river ecosystem damaged.

d. Impacts of unregulated human interference

Impacts of unregulated human interference in the river basin can lead to pollution of water resources; flood; water resources deficiency; loss of biodiversity; etc.

Water is life. Water as a resource, are critical to sustainable development. It is a prerequisite for human health and well-being. Ten thousand to twenty thousand people mainly children die every day from water-related diseases. A child dies every 15 seconds from a disease caused by lack of access to safe water, inadequate sanitation and poor hygiene (Gijzen, H., 2014).

According to United Nations (2012), by 2025, 60 % of people in the world will live without enough water supplies. Water scarcity already affects every continent. Around 1.2 billion people, or almost one-fifth of the world's population, live in areas of physical scarcity, and 500 million people are approaching this situation. Another 1.6 billion people, or almost one quarter of the world's population, face economic water shortage (where countries lack the necessary infrastructure to take water from rivers and aquifers). Around 700 million people in 43 countries suffer today from water scarcity. By 2025, 1.8 billion people will be living in countries or regions with absolute water scarcity, and two-thirds of the world's population could be living under water stressed conditions. With the existing climate change scenario, almost half the world's population will be living in areas of high water stress by 2030, including between 75 million and 250 million people in Africa. In addition, water scarcity in some arid and semi-arid places will displace between 24 million and 700 million people. Sub- Saharan Africa has the largest number of water-stressed countries of any region. Figure 8 shows the global water scarcity.

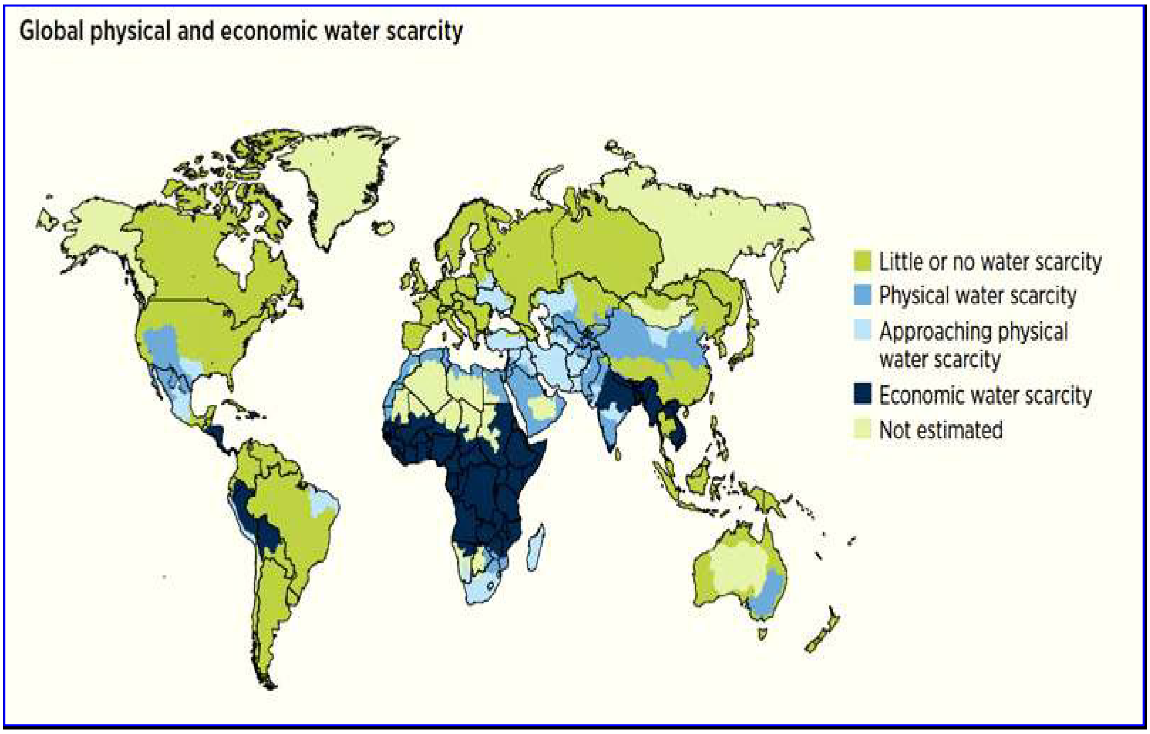


Figure 8: Global physical and economic water scarcity (after World Water Development Report 4)

Figure 9 shows the depleting water resources in some countries.

Figure 9: Is this the future of our water resources? (image may be subject to copyright)

3.1 Examples of Water Resources Management Issues

There are many water resources management issues as illustrated in diagrams in Figure 10. Table 1 shows the ranking of the water issues in Malaysia.

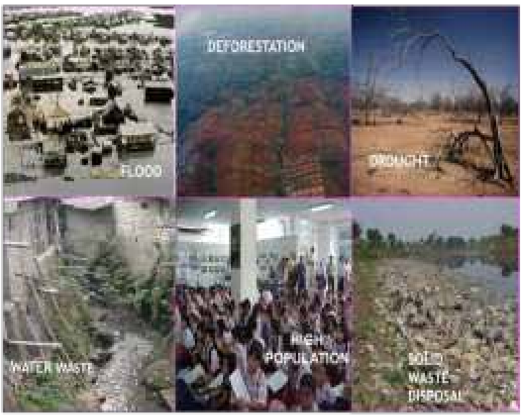


Figure 10: Water resources management issues (image may be subject to copyright)

Table 1: Ranking of water related issues in Malaysia (after DID, 2009)

Ranking	Water-Related Issues
1	River Water Quality
1	Catchment/Landuse Management
1	Flooding
2	Potable Water Supply
3	Institutional Arrangement
4	Segmented Management
5	River Corridor Management
6	Wetlands Management
7	Water Borne Diseases
8	Biodiversity
9	Drought
10	Environmental Flow

The issues of river pollution can be seen in Figure 11.

Figure 11: Polluted rivers in city area

3.2 Water Issues Challenges

Approximately 71.23% of all illnesses in developing countries are caused by poor water and sanitation conditions. It is common for women and girls to have to walk several kilometers every day to fetch water for their families. Once filled, water jugs can weigh as much as 20 kg (44 lbs).

a. Water and people (Gijzen, H., 2014):

- 0.8 billion people are without improved water.
- 2.5 billion people without improved sanitation.
- 5 billion live near polluted water.
- Millions (often children) die from water borne disease every year.
- 1 billion people hungry.

b. Water quantity and quality (Gijzen, H., 2014):

- Sharp increase in worldwide water use.
- Depletion of groundwater sources.
- Food security.
- Climate change – extreme events (e.g. flood, drought).
- Rapid urbanization – water footprints (the amount of water used by an individual, community, business, or country).
- Massive pollution of water resources: sewage, nitrogen, pesticides, endocrine disruptors.
- Loss of associated ecosystems and biodiversity.
- Public health risks.

c. Ten Key Global Challenges, where water is the defining issue (Gijzen, H., 2014):

- Poverty eradication.
- Pollution.
- Population growth and urbanization.
- Food security and sustainable production.
- Old and New diseases.
- Disasters.
- Water and environmental resources.
- Climate change.
- Peace and security.

Opening of land for development in highland and wetland can result in deterioration of water resources. Forest area in the highland functions as an area for rain storage and supply of clean water. The highland area also provided sediment/nutrient for rivers and their ecosystems. While the wetland function as water regulator in the catchment area. During heavy rain and high water discharge the wetland will absorb some amount of water and this will reduce the magnitude of flooding.

With the increasing land-use changes and use of water, the quality of runoff water and discharge wastewater, become poorer, and will enter the river. Any clean-up strategy must target the sources, which have the greatest impact on water quality, as well as the most important sources of water quality degradation.

Various human activities at the upstream and middle reaches of rivers often result in the increasing drainage of sewage disposal and the pollutant substances. In the world, the management of products/outputs from production forest and green area as well as from pervious area or with less or without proper source control on the water environment, resulted in the increase of the rainwater runoff to the drainage and river systems. This in turn will cause an increase in flood magnitude, erosion, and sedimentation with more impacts to the surrounding area. It can also result in the increase of water resources pollution. Therefore, there is a need for more awareness on the degradation of water quality in the upstream/middle reaches of river catchment and the increase of floods events and magnitude.

4. Understanding River Ecology and Ecosystem

According to Cary Institute (2017), ecology was originally defined in the mid-19th century, when biology was a vastly different discipline than it is today. The word "ecology" was coined in 1866 by the German scientist Ernst Haeckel (1834–1919) who defined ecology as the study of the relationship of organisms with their environment. In the intervening century and a half, other definitions of ecology have been proposed to reflect growth of the discipline, to found new specialties, or to mark out disciplinary territory. There are three pervasive definitions of ecology. The first definition stems from the Haeckelian form - the study of the relationship between organisms and environment. The second definition, which is perhaps the most commonly repeated, considers ecology to be the study of the distribution and abundance of organisms (Andrewartha and Birch, 1954). The third definition focuses ecology on the study of ecosystems (Odum, 1971).

Cary Institute (2017) further elaborated that the three kinds of definitions each have their limits and advantages. The hallmark of ecology is its encompassing and synthetic view of nature, not a fragmented view. In third context, definition of ecology is a blend of the second and third definitions. This new overarching definition attempts to bridge the spectrum of ecological approaches, with the goal of promoting synthesis and integration. In another definition ecology is the study of the relationships between living organisms, including humans, and their physical environment; it seeks to understand the vital connections between plants and animals and the world around them.

The ecology of the river refers to the relationships that living organisms have with each other and with their environment – the ecosystem. River ecosystems have flowing water that is mostly unidirectional, a state of continuous physical change and many different and changing microhabitats (Science Learning Hub, 2014). The following unifying characteristics make the ecology of running waters unique among aquatic habitats.

- Flow is unidirectional.
- There is a state of continuous physical change.
- There is a high degree of spatial and temporal heterogeneity at all scales microhabitats).
- Variability between lotic systems is quite high.
- The biota is specialized to live with flow conditions.

Ecosystem, the complex of living organisms, their physical environment, and all their interrelationships in a particular unit of space. An ecosystem can be categorized into its abiotic constituents, including minerals, climate, soil, water, sunlight, and all other nonliving elements, and its biotic constituents, consisting of all its living members. Linking these constituents together are two major forces: the flow of energy through the ecosystem, and the cycling of nutrients within the ecosystem. The fundamental source of energy in almost all ecosystems is radiant energy from the Sun. The energy of sunlight is used by the ecosystem's autotrophic, or self-sustaining, organisms. Consisting largely of green vegetation, these organisms are capable of photosynthesis—i.e., they can use the energy of sunlight to convert carbon dioxide and water into simple, energy-rich carbohydrates. The autotrophs use the energy stored within the simple carbohydrates to produce the more complex organic compounds, such as proteins, lipids, and starches, that maintain the organisms' life processes. The autotrophic segment of the ecosystem is commonly referred to as the producer level. (Encyclopedia Britannica, n.d.)

Biodiversity affects ecosystem function, as do the processes of disturbance and succession. River biodiversity is about ecosystem: flora-fauna, natural river courses, river inhabitants, relationship between river bank and the river channels. It is about conservation and creating back the natural river environment such as rapids, meandering nature of river system, ponds for fish and aquatic life, environmental friendly river corridor, the suitable environment for flora and fauna and so on. Ecosystems provide a variety of goods and services upon which people depend; the principles of ecosystem management suggest that rather than managing individual species, natural resources should be managed at the level of the ecosystem itself. Classifying ecosystems into ecologically homogeneous units is an important step towards effective ecosystem management.

The ecosystem of a river is the river viewed as a system operating in its natural environment, and includes biotic (living) interactions amongst plants, animals and micro-organisms, as well as abiotic (nonliving) physical and chemical interactions. Figure 12 shows an example of river ecosystem.

Figure 12: This stream together with its environment can be thought of as forming a river ecosystem (after RFMCJ and DID, 1996)

Further explanation on the important of natural river ecology and ecosystem are illustrated in the diagrams in Appendix B.

4.1 Zoning of Rivers

All rivers, regardless of their type, have the same stages of structural changes from source to delta (Mihov and Hristov, 2011). The profile of every river can be divided into three zones (Figure 13): (1) **Source zone** (headwaters) - mountain streams that slope rapidly downhill and form V-shaped river valleys, often forming waterfalls. These rapids shape and carry large size sediments downstream; (2) **Transfer zone** - characterized by a lower altitude. The flow velocity is slower, the river bed becomes wider, and meanders form. Some of the larger sediments settle at the interim area between the source zone and the transfer zone, thus forming the so-called sediment cones. Other sediments are carried further downstream. Erosion and deposition processes are in equilibrium in the transfer zone. (3) **Deposition zone** - of rather low slope; flow velocities are slow, forming wide meanders. Most of the sediments, including the finest ones, settle in this area. The river mouth often opens into a wide delta bottomed by fine sediments, and the river splits into many arms. Zoning of rivers into water catchment and development zones and still preserving its natural ecosystem is shown in Figure 14.

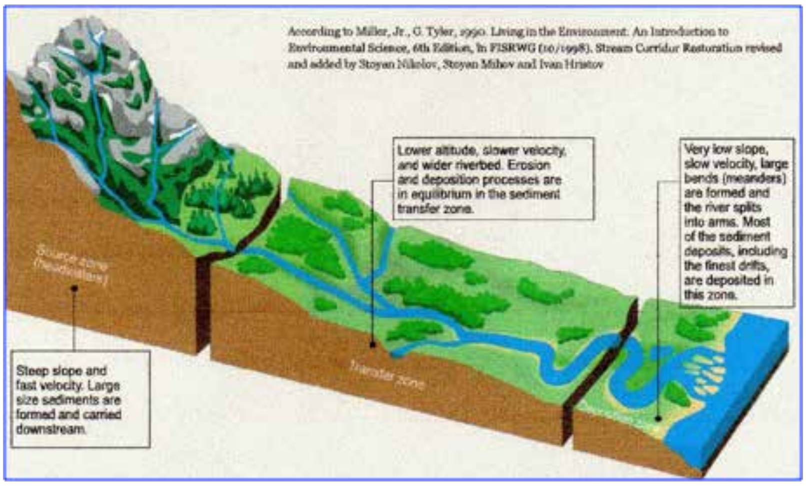


Figure 13: Length-wise zoning of a river (after FLSRWG, 1998; Mihov and Hristov, 2011)

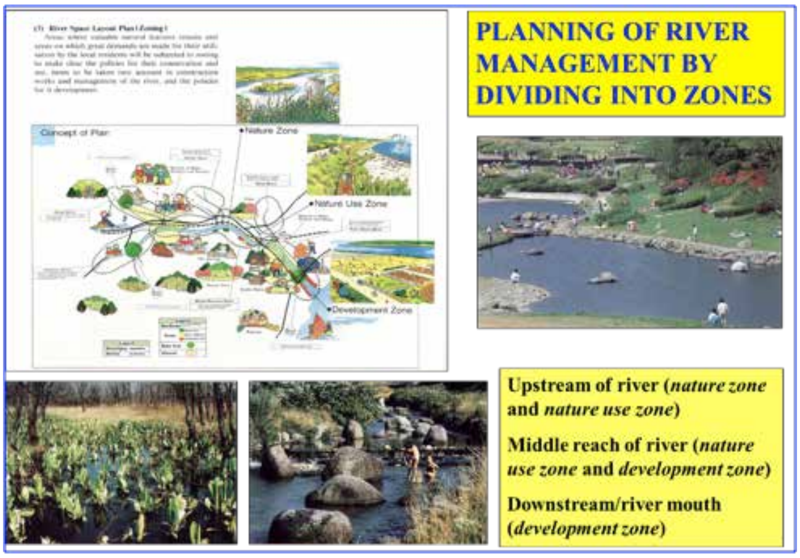


Figure 14: Classification of river into 3 zones (example from Japan)

4.2 Ripple and Pool

Regardless of the form of their beds, all rivers have equidistant sequencing of shoals and deeper sections, called riffles and pools. They are linked to the river midstream - a line which benchmarks the deepest section of the river and where the water flows fastest. Pools are formed in the midstream, next to the outside bank of a watercourse bend. Riffles are formed between two bends where the midstream goes from one river bank to the other. The distance between two pools or two riffles - a common feature for all rivers is 5 to 7 times the width of the river, measured at its highest water level. The sequencing of pools and riffles within a river section, and the existence of various habitats illustrates the variety of life adapted to both fast and slow currents and serves as a precondition for a well-functioning river ecosystem. Figures 15 to 19 illustrates ripple and pool in a river system.

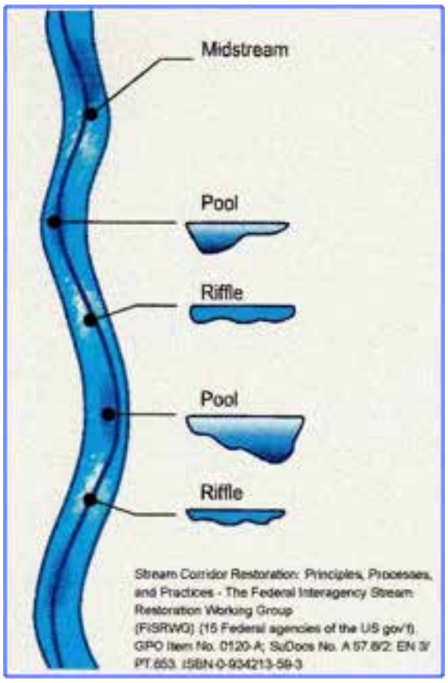


Figure 15: Regular sequencing of pools and riffles (after FLSRWG,1998; Mihov and Hristov, 2011)

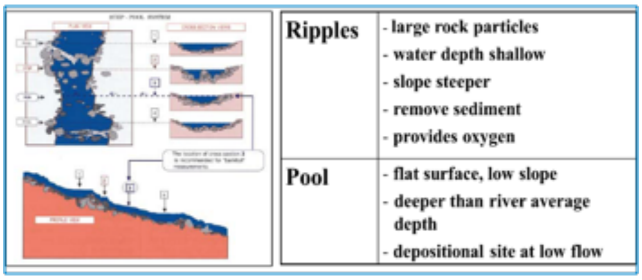


Figure 16: Channel features with ripples and pools

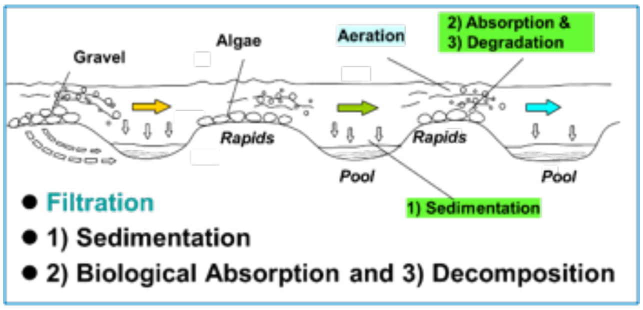


Figure 17: Self-purification mechanisms of rivers

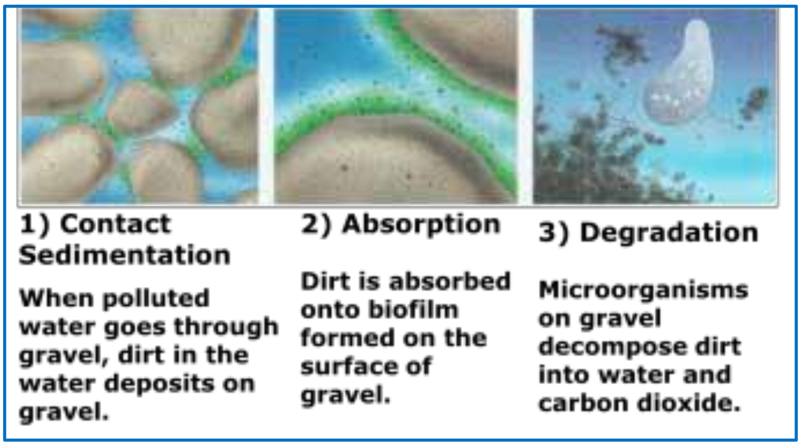


Figure 18: Self-purification mechanisms of rivers

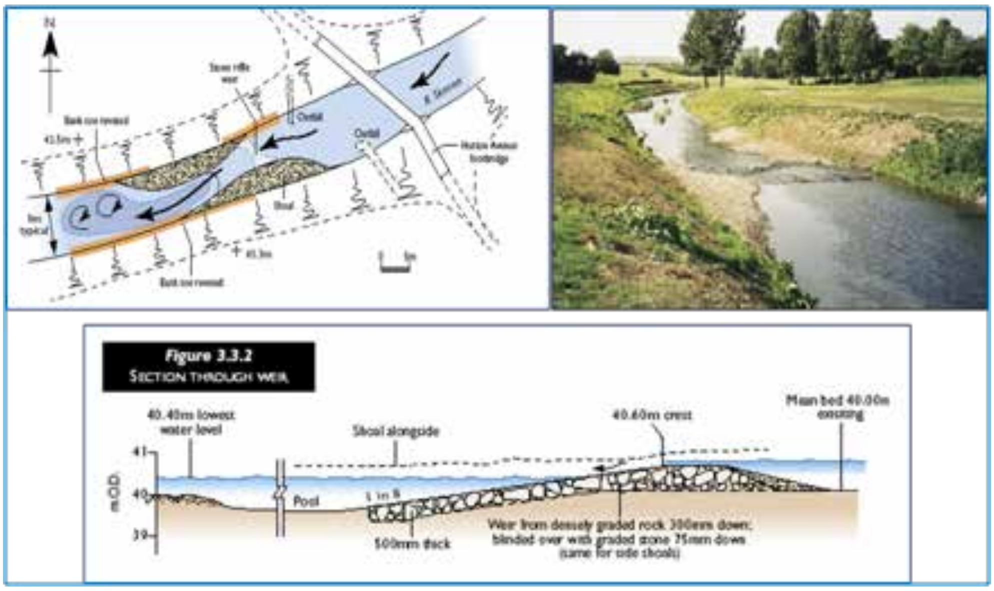


Figure 19: River ecology: creating stone riffle (after USDA, 2007)

4.3 Relation between River and Groundwater

The water level of most rivers varies greatly depending on the seasons/periods. The seasonal increase of water level has an important role in supporting river ecosystems. Rivers often link to adjacent wetlands only at high water level, which is often the only possibility for fish populations to migrate. Unique vegetal systems develop on the banks of rivers with higher variations of water levels, especially in the lower course; they are very well adapted to such conditions. These are the floodplain forests (Mihov and Hristov, 2011).

The riverbed usually lies on water-saturated, old river sediments. This groundwater runs to or from the river down the river valley. The stream in the riverbed is part of the water flow running through the valley. The level of groundwater depends on the level of water in the riverbed. In dry periods or during periods no rain, surrounding areas drain into the river bed and groundwater runs towards it. During flooding, the groundwater direction may reverse (Figure 20).

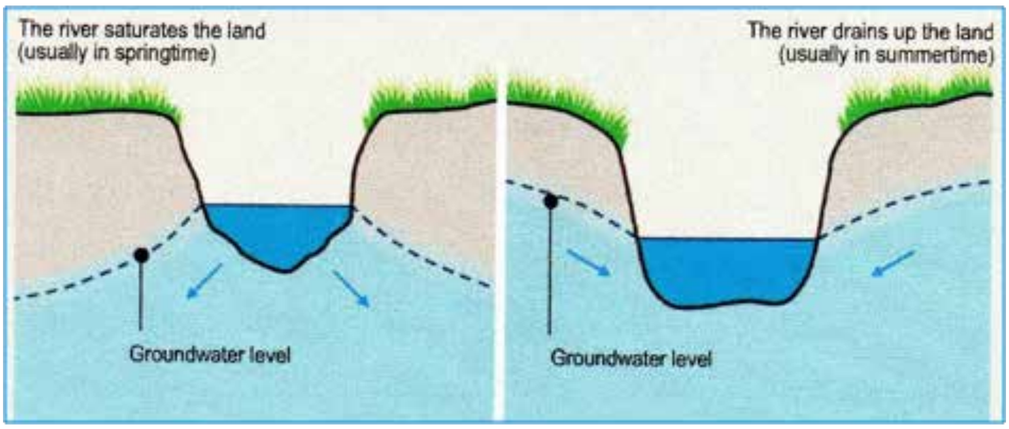


Figure 20: Relation between river and groundwater (after FLSRWG, 1998; Mihov and Hristov, 2011)

4.4 Floodplain and Riparian Zone

Floodplain provides temporary storage for floodwaters, storage for sediment from watershed to settle before flowing into the river, space for channel to migrate over time, etc. The floodplain is theoretically divided into two parts: hydrologic floodplain and topographic floodplain (Figure 21). The hydrologic floodplain is an area inundated with water. It could be several times each year. The topographic floodplain includes the hydrologic floodplain up to the altitude reached by a flood peak of given frequency. The topographic floodplain is used in spatial planning and development, and all the activities therein must consider the risk of flooding. For instance, no human settlements or important infrastructure facilities should be developed in the floodplain (Mihov and Hristov, 2011).

The floodplains, especially those downstream, are dynamic systems with many various components that undergo a continuous process of formation or disappearance (Figures 22, 23 and 24). Figure 23 shows the landforms and deposits of a floodplain. Topographic features on the floodplain caused by meandering streams. Figures 24 (a) and (b) show the schematic of the flood-pulse concept. It shows a vertically exaggerated section of a floodplain in five snapshots of an annual hydrological cycle. The left column describes the movement of nutrients. The right column describes typical life history traits of fish (Bayley, 1995)

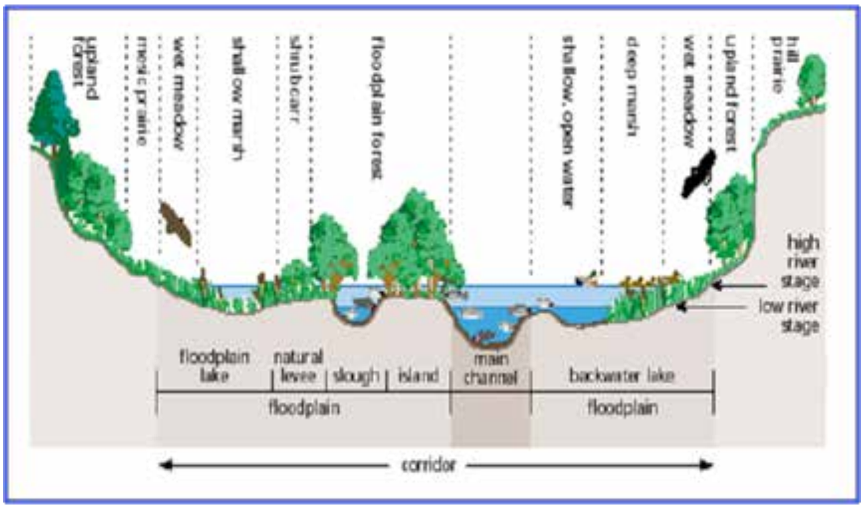


Figure 21: River floodplain (after FLSRWG, 1998)

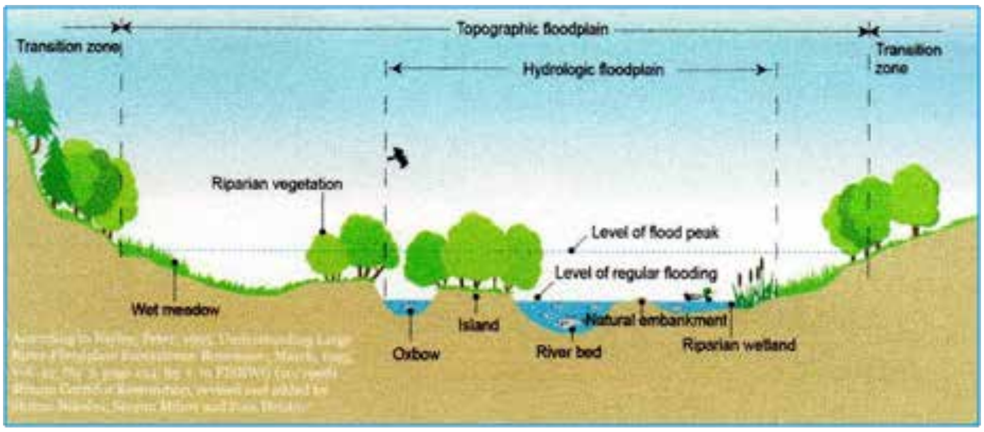


Figure 22: Transverse structure of the river corridor (after FLSRWG, 1998; Mihov and Hristov, 2011)

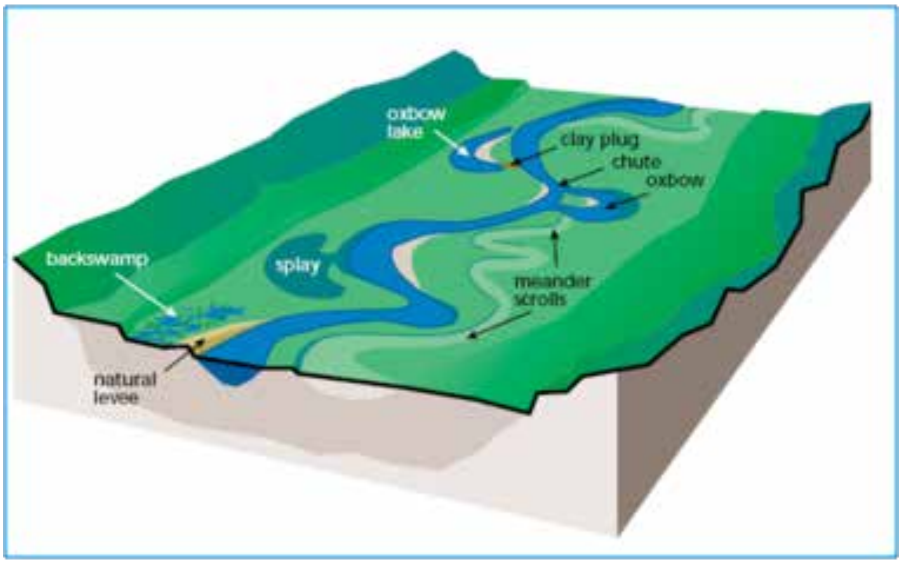
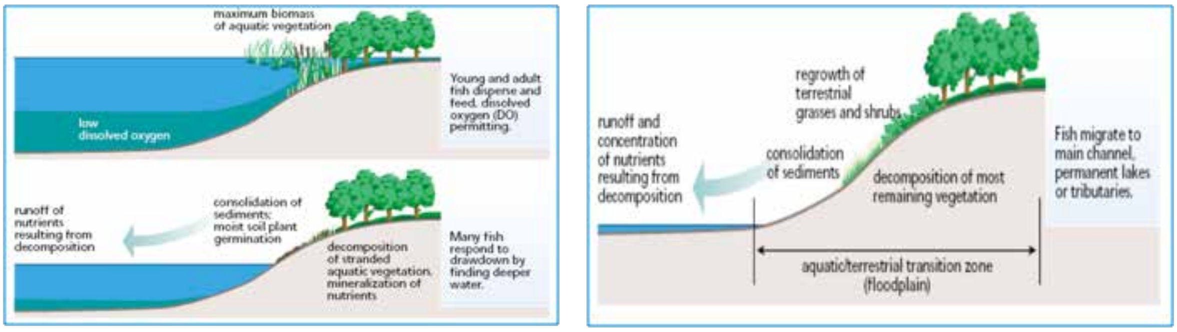


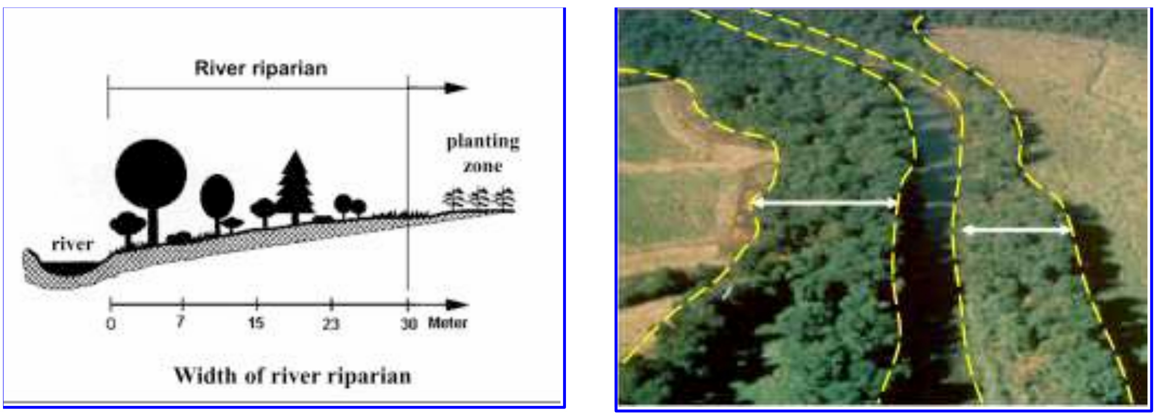
Figure 23: River components in floodplains (after FLSRWG, 1998; Mihov and Hristov, 2011)



(a) (b)

Figure 24: Schematic of the flood-pulse concept (after FLSRWG, 1998)

In Asia there are different types of riparian vegetation, but the interactions between hydrology and ecology are similar as occurs in other geographic areas. Figures 25 to 27 show the concept and examples of river riparian zones/areas.



(a) (b)

Figure 25: River riparian zones and areas

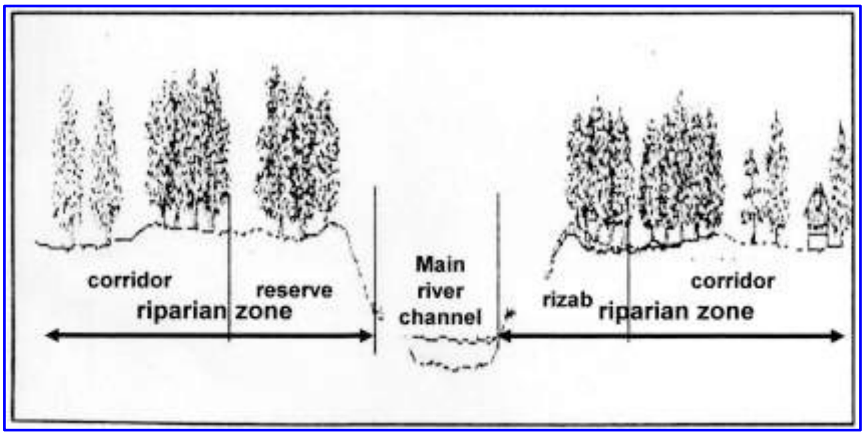


Figure 26: A sketch of cross-section showing river reserves and riparians

(a)

(b)

Figure 27: Examples of river riparians in Japan

5. Understanding River Hydraulics

Understanding natural channel (river) behavior, its ecosystem, hydraulics is of utmost important. In any sustainable water resources quantity and quality obligation, management, enhancement, maintaining channel ecosystem and the natural hydraulics of flow is important. The knowledge in aspect of science, technology and innovation are needed by the policy makers, managers, practitioners, authorities (at federal, states and local), consultants, academia, students, even for the community in some form (Roseli, et al., 2017b).

This section describes the art and science of river engineering (Figure 28). The focus will be on a representative of natural river ecosystem and compound channel which can be used in the planning, design, implementation and monitoring of projects such as river cleaning programme, river restoration project, river of life, stormwater management, flood mitigation, drainage control, etc.

5.1 Recommended River Section for Sustainable Water Ecosystem Management

Figure 29 shows an example of a natural river ecosystem with main channel and floodplain. The recommended typical river section based on hydraulic river studies is shown in Figure 30. This typical river section is closer to the shape of a natural river and recommended to be use in the design of river section. The representative river section was obtained from the study of the relationship between wave-speed and discharge (Figures 31 and 32), attenuation with discharge (Figure 32), forces acting on compound channel, momentum transfer between inbank, transition and overbank flows and water levels.

Figure 28: The art and science of river engineering (after Shiono and Knight, 1996)

Figure 29: An example of a natural river ecosystem

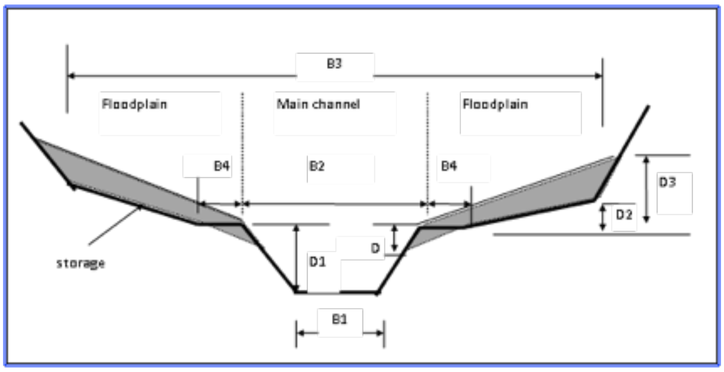


Figure 30: Recommended typical river section (after Roseli, 1999)

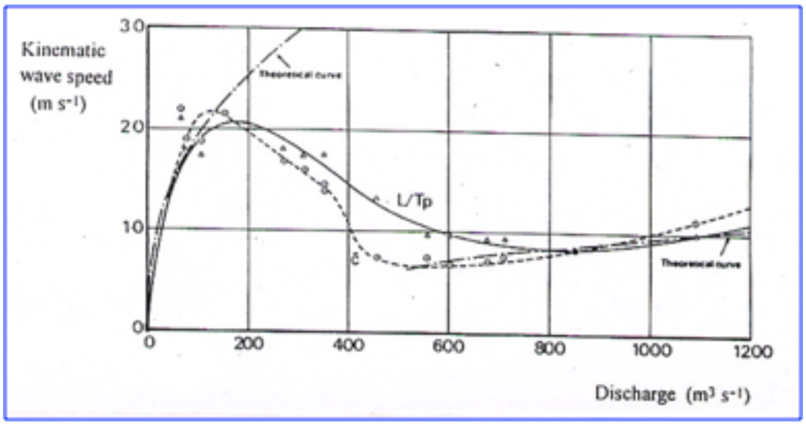


Figure 31: Example of wave speed discharge – curve for River Wye, Erwood to Belmont Reach, United Kingdom (after NERC, 1975)

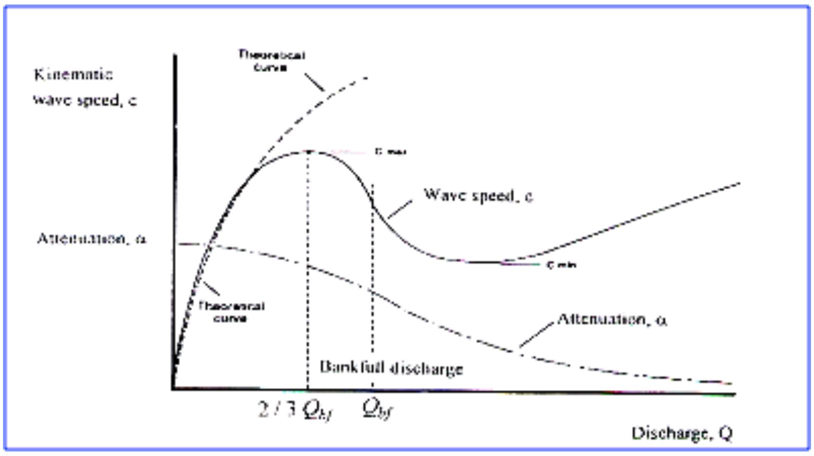


Figure 32: Typical kinematic wave speed-discharge and attenuation-discharge curves

Plotting wave speed discharge relationship in using Figure 32, its shape obtained is as shown in Figure 33 which is similar to Figures 31 and 32.

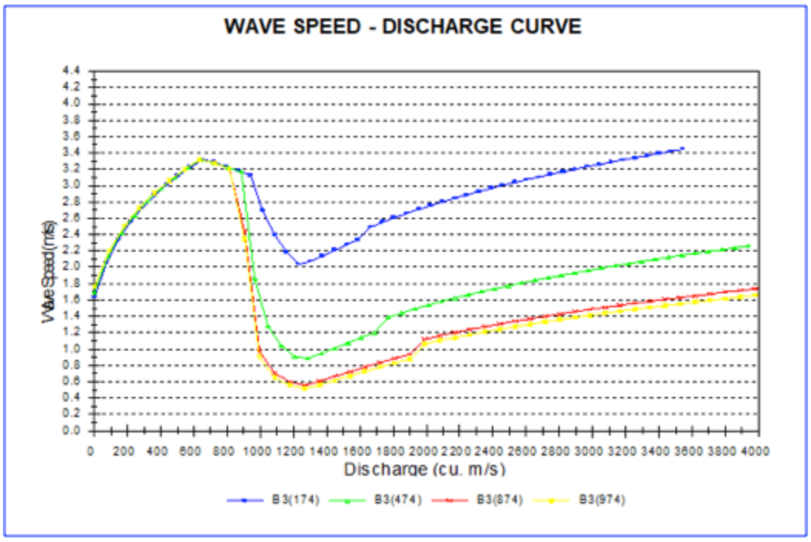


Figure 33: Example of wave speed-discharge curve for different floodplain width (after Roseli, 1999)

There is a resistance to the flow. In determining the designed discharge, the conventional resistance equations such as Manning, Chezy, and Darcy-Weisbach can be used effectively for the main channel. Many natural rivers have floodplains beside the main river channel and in times of flood these floodplains may act as a store for water. In overbank flow, the main river channel flow is usually affected by the floodplains and the overall conveyance capacity is reduced. Besides resistance there is also an area of storage to be included in the design of discharge and water level for flows above bankfull in the transition zone and overbank flow (Figure 30). The used of the traditional methods such as Manning's resistance equation in determining flood discharge and in the relationship of stage – discharge has been known to give large errors in overbank flows i.e. when flows exceed bankfull flow into the floodplains. This is because the traditional methods do not consider the mechanics and hydraulics of two stage channel flow. Also, the storage effect at different levels of flow in the floodplains has not been considered. There is a large variation of Manning's coefficient 'n' as shown in Figure 34.

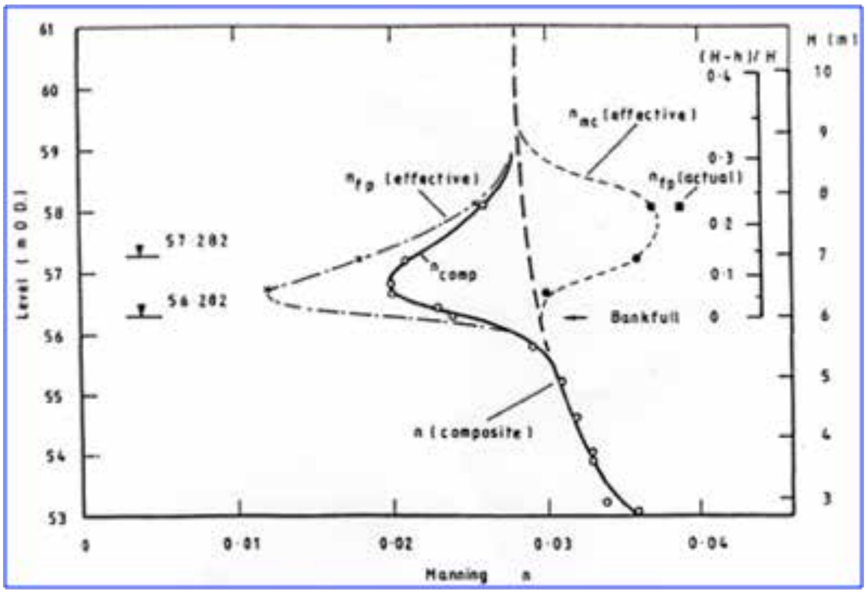


Figure 34: Variation of Manning's 'n' resistance coefficient for overbank flow at Monford, River Severn, United Kingdom (after (after Shiono, et al., 1989)

One of the methods that addressed this issue, an improvement to the traditional methods is in using Ackers' coherence equation (Ackers, 1993). Ackers, applied the concept of 'coherence' defined as the ratio of the basic conveyance calculated by treating the channel as a single unit, with perimeter weighting of the friction factor, to that calculated by summing the basic conveyances of the separate zones. Thus, the coherence, *COH*, is defined as:

$$COH = \frac{\sum_{i=1}^{i=n} A_i \sqrt{\left[\sum_{i=1}^{i=n} A_i \Big/ \sum_{i=1}^{i=n}(f_i P_i)\right]}}{\sum_{i=1}^{i=n}\left[A_i \sqrt{\left(A_i/(f_i P_i)\right)}\right]} \qquad (1)$$

where, P is the wetted soil perimeter of flow cross-section, *A* is the cross-sectional area, *f* is given by $8gRS / U^2$, where, *R* is the hydraulic radius, *S* is the channel slope and *U* is the average flow velocity through cross-section. In using Manning's equation, the coherence equation becomes:

$$COH = \frac{(1+A_*)^{3/2} \Big/ \sqrt{\left(1+P_*^{4/3} n_*^2 / A_*^{1/3}\right)}}{1 + A_*^{5/3} \big/ n_* P_*^{2/3}} \qquad (2)$$

where, $A_* = N_f\, A_f / A_c$, $P_* = N_f\, P_f / P_c$, $n_* = n_f / n_c$ and N_f is the number of floodplains.

The closer to unity the *COH* approaches, the more appropriate it is to treat the channel as a single unit, using the overall geometry. Where the coherence is much less than unity then discharge adjustment factors are required in order to correct the individual discharges in any sub-area. It appears from experimental studies of overbank flow that different discharge adjustment factors (*DISADF*) are required in at least four distinct regions of depth as shown by a typical set of data in Figure 35.

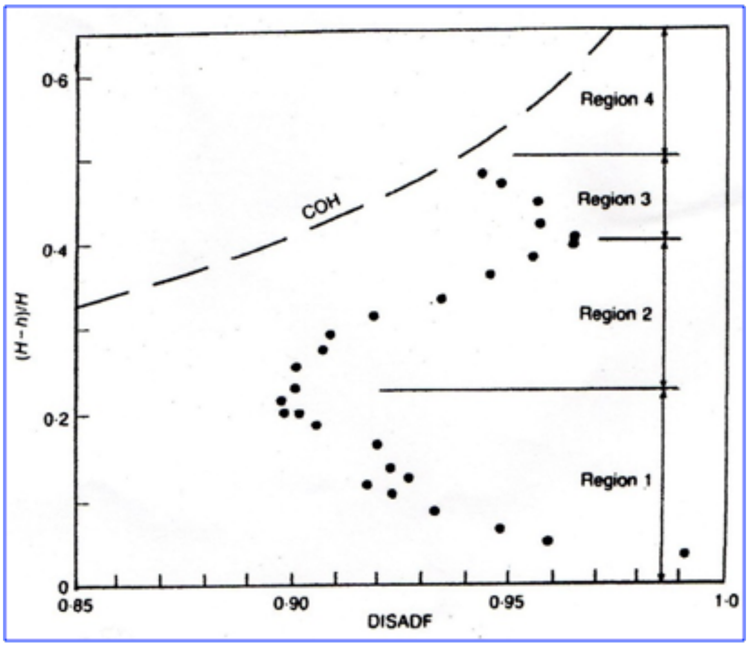


Figure 35: Discharge Adjustment Factor, DISADF, for FCF tests, Series 2 (after Ackers, 1993)

The comparison of stage - discharge relationship between using geometrical divided channel method (Manning's equation), Ackers' coherence equation and ISIS steady flow run are shown in Table 2. ISIS uses conveyance tables with vertical divided channel method for overbank flow. The corresponding discharges calculated from the geometrical divided channel method and using Ackers' coherence equation are shown in Tables 2(a) and 2(b). These discharges were used to obtain the normal flow depths from the ISIS steady flow run. Their comparison with the tested flow depths are shown in Tables 2(a) and 2(b). The tested flow depths were then used in an ISIS steady flow run to obtain the corresponding discharges, which were then compared with those using Ackers' coherence equation and the divided channel method, as shown in Table 2(c).

The stage - discharge curves of Figure 39 shows the differences in stage for the discharges calculated using Ackers' coherence equation. The comparison of results showed that the divided channel method and ISIS Flow influence the normal flow depths for overbank flows. This is especially so at low overbank flow when the results of using ISIS is compared with the divided channel method and at higher overbank flow when comparing using ISIS Flow with Ackers' coherence equation, as shown in Tables 2(a) and 2(b), respectively, and Figure 36.

Table 2: Comparison of stage-discharge relationship between using divided channel method, Ackers' coherence equation and ISIS steady flow run using Ackers' channel (after Roseli, 2004b)

(a) Normal channel depths for corresponding Q from divided channel method

No.	Discharge Q (m^3/s)	Channel Depth (m)		
		Using Divided Channel Method	Using ISIS	Differences (%) ((4)-(3))/(3)
(1)	(2)	(3)	(4)	(5)
1	16.900	1.500	1.500	0.00
2	23.470	1.750	1.690	-3.43
3	31.967	2.000	1.936	-3.20
4	42.037	2.250	2.227	-1.02
5	53.519	2.500	2.479	-0.84
6	66.314	2.750	2.718	-1.16
7	80.344	3.000	2.980	-0.67

(b) Normal channel depths for corresponding Q from Ackers' coherence equation

No.	Discharge Q (m^3/s)	Channel Depth (m)		
		Using Divided Channel Method	Using ISIS	Differences (%) ((4)-(3))/(3)
(1)	(2)	(3)	(4)	(5)
1	16.900	1.500	1.500	0.00
2	20.638	1.750	1.608	-8.11
3	26.369	2.000	1.774	-11.30
4	33.541	2.250	1.981	-11.96
5	41.901	2.500	2.223	-11.08
6	51.354	2.750	2.439	-11.31
7	61.808	3.000	2.634	-12.20

(b) Normal channel depths for corresponding Q from Ackers' coherence equation

No.	Channel Depth (m)					
	Using Acker's Equation	Using ISIS	Using Divided Channel Method	Difference (%) ((3)-(2))/(2)	Difference (%) ((4)-(2))/(2)	Difference (%) ((3)-(4))/(4)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1.500	16.900	16.900	16.900	0.00	0.00	0.00
1.750	20.638	25.530	23.470	23.70	13.72	8.78
2.000	26.369	34.180	31.967	29.62	21.23	6.92
2.250	33.541	42.840	42.037	27.72	25.33	1.91
2.500	41.901	54.660	53.519	30.45	27.73	2.13
2.750	51.354	68.050	66.314	32.51	29.13	2.62
3.000	61.808	81.450	80.344	31.78	29.99	1.38

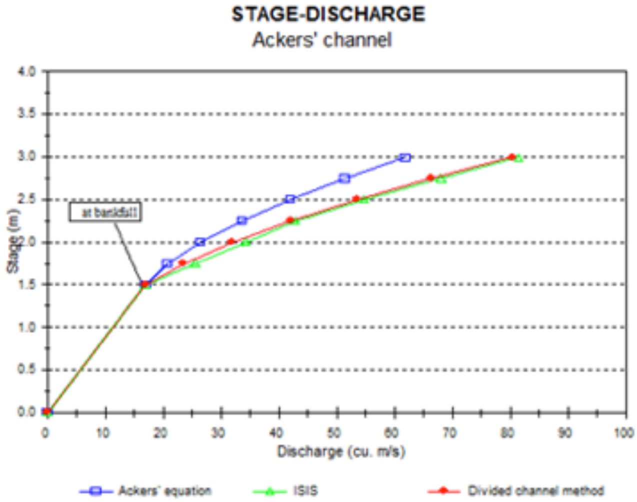


Figure 36: Comparison of stage-discharge relationship between Ackers' equation, v ertical divided channel method and ISIS steady flow run for Ackers' channel (same stage) (after Roseli, 1999, 2004b)

A comparison of discharges obtained by the steady flow run of ISIS (one version of ISIS Flow software (HR Wallingford/William Halcrow, 1995)), and divided channel methods and those calculated by Ackers' coherence equation for the same depths of flow showed differences of about 30 % especially at higher overbank flows. Comparison ISIS with the divided channel method showed differences by as much as 9 % for a low overbank flow but small differences at higher overbank flow. See Table 2(c). This means that when using the divided channel method and this particular version of ISIS for overbank flows, one would expect higher discharges by up to 30 % than reality. For the same discharges, as shown in Figure 36, the divided channel method and ISIS showed a much reduced water level. Flood levels are therefore under predicted by the divided channel method and ISIS. Out of these three methods, those obtained from ISIS gave the worst results as shown in Table 2 and Figure 36 (Roseli, 1999, 2004b).

The reason for the differences in the overbank flow cases is due to the way in which ISIS calculates the discharge in compound sections, using conveyance tables and the vertical divided channel method. Using simple vertical boundaries, the method is known to give erroneous results. Therefore, river engineers in using software and Manning's equation, the overbank discharges produced should be treated with a certain amount of caution. It is advisable after obtaining the results of discharges and water level, to check the results with other known methods such as Ackers' before decision are made on the values to be used for the suggested river improvement works (Roseli, 2004b). It is recommended that a higher design water level should be used than those obtained from using Manning' equation and software for the same overbank flow discharge unless in the calculations the cross-section used include the storage function of the natural river ecosystem.

5.2 Compound Channels

The basic form of a two-stage (compound) channel is a central deep channel (main channel) with symmetrical horizontal berms. The berms (floodplain) come into action at high flows. The terminology for a typical section is given below (Figure 37).

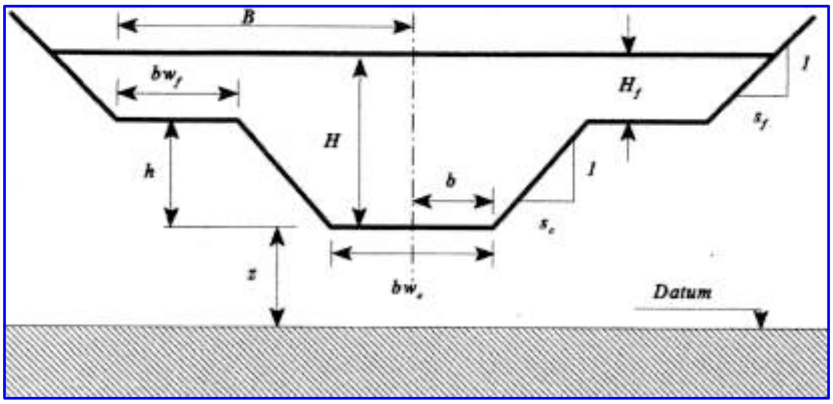


Figure 37: A typical trapezoidal compound channel (HR Wallingford/William Halcrow, 1996)

In reality the cross-section may be composed of several distinct sub-sections each having a different roughness. In simple channels, the roughness may vary along the wetted perimeter, but the mean velocity can still be computed by a uniform-flow formula without actually sub- dividing the section.

Applying the Manning equation to such channels, it is sometimes necessary to compute an equivalent 'n' value for the entire perimeter and use this equivalent value for the computation of the flow in the whole section.

The different velocities in the channel and on the floodplains create areas of strong shear and turbulence at the channel floodplain interface. The effect of these additional forces is to generate additional head loss. This usually leads to over estimation of flows because of the interaction between the main channel and the slower moving floodplain flows.

The cross-section of compound channel may be compared of several distinct sub-sections (e.g. Figure 38) with each sub-section different in roughness from the others. The side channels (floodplains) are usually rougher than the main channel, so the mean velocity in the main channel is greater than the mean velocities in the floodplains.

Manning's formula may be applied separately to each subsection in determining the mean velocity of the subsection. Then, the discharges in the subsections can be computed. The total discharge is equal to the sum of these discharges.

The mean velocity for the whole channel section is equal to the total discharge divided by the total water area. Owing to the differences that exist among the velocities of the subsection, the velocity – distribution coefficients of the whole section are different from those of the subsections.

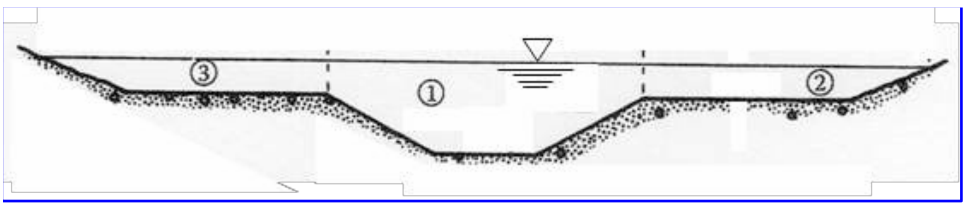


Figure 38: Compound channel divided into sub-sections

5.3 Overbank Hydraulics of Flow

Typically, a river serves as a passageway of stormwater including flood water and balancing of sediment emanating from the catchments, flowing ultimately to the sea. Rain falling in a river basin becomes surface run off and is drained to the sea. The percentage is lower in the rural areas, and higher in the urban areas.

From time to time, rain events heavier than normal falls over an extended period of time. Such events become a factor contributing to the occurrence of flood events when the lower reaches lack the capacity to convey safely the floodwater to the sea, causing bank overflow and hence inundating the low-lying areas on the floodplains (Roseli, 2006). The flood risk is much higher when the rain coincides with incidences of high tide.

As a flood wave passes through a river reach, the peak of the outflow hydrograph is usually attenuated and delayed due to channel resistance and storage capacity (Bras, 1990). This is shown diagrammatically and in exaggerated form in Figure 39. The Figure showed some important features which can be identified as a translation in time of the hydrographs for flood event between the Location A (upstream) and Location B (downstream); a decrease in the peak discharge and a deformation of the hydrograph. The typical shape of the outflow hydrograph at Location B represented flow in the main channel only. For two stage channel i.e. river with main channel and floodplains as the usual case for a natural river, the shape of the hydrograph is different for flow in the floodplains (overbank flow) as shown in Figure 40. The time of peak of the peak outflow is delayed further and hence more attenuation. Much of these explanations with actual river system flood hydrographs can be obtained from Price (1995).

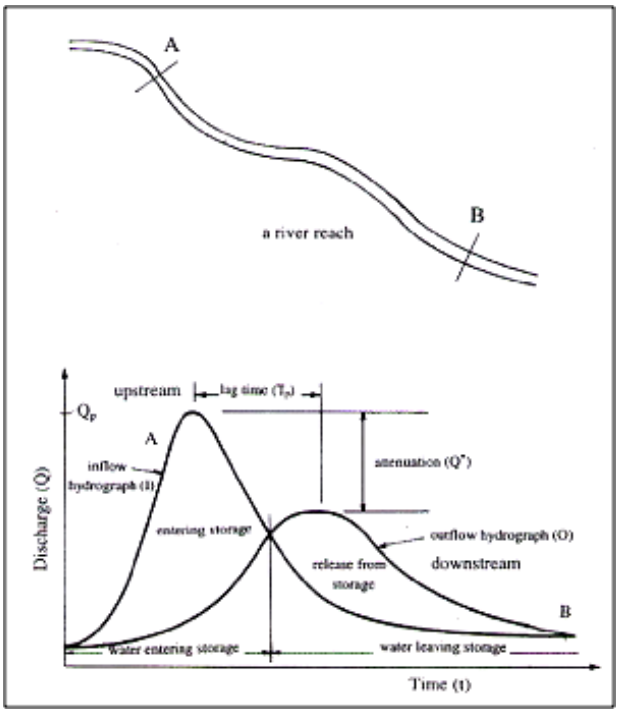


Figure 39: Flood hydrograph routing (Roseli, 1999, 2004b)

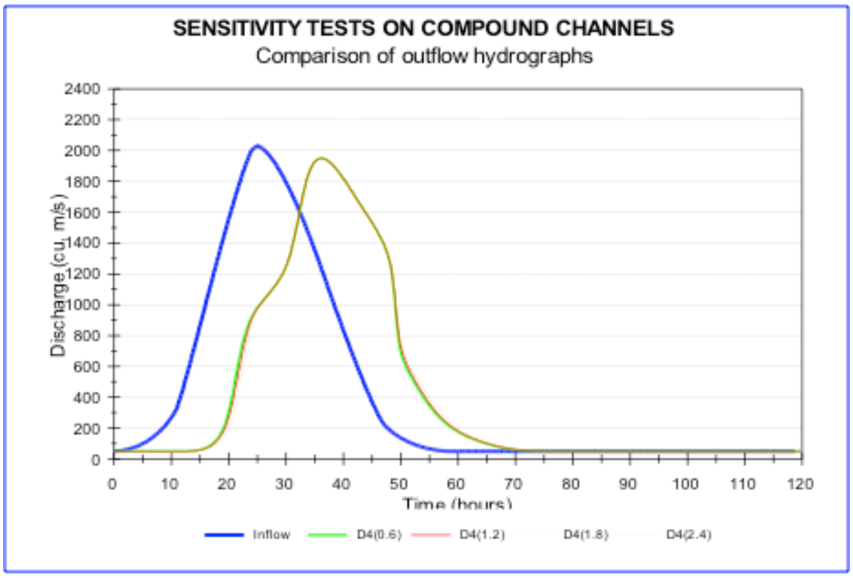


Figure 40: Example of flood hydrograph in two stage channel (compound channel) (Roseli, 1999, 2004b)

Higher discharges will occasionally occur in rivers, and cause the channel to flow in an overbank condition, thereby increasing the flow area, depth and width. The channel cross- section is now different from the inbank flow, incorporating the main river channel and the adjacent floodplains. However, it is still an open channel with a more complex geometry, roughness and planform. The floodplains are therefore an integral part of the whole river system. It should be recognized that for overbank flow, not only does the cross-section shape change significantly from its inbank shape, but also the streamwise pathways for flow may alter considerably (Knight and Shiono, 1996). In nature, there is a continuum of hydraulic processes coming into action above the bankfull level. There is also a significant increase in the complexity of the flow behavior once overbank flow starts. This is to say, once the river flows in out-of-bank manner as frequently occurs in flood flow conditions, then the discharge in the whole channel, the main river and its associated floodplains, is considerably more difficult to calculate than when the river is flowing wholly inbank.

A conceptual model of the interaction process that occurs between the main channel and any floodplain flows in the understanding of the real physics of the flow are given in Figure 41 which demonstrated the complexity of the floodplain hydraulics. Various three-dimensional structures are illustrated, each with their own length and time-scale. At the top of the main river channel bank at the edge of the floodplain, there are large interrelated vortex structures which are individually important.

One dominant feature at the water surface is the vortices with vertical axes which develop in any highly sheared zone between two co-flowing streams at different velocities. These are indicated as a bank of vertical 'interface vortices'. It is the periodic nature of these vortices that accounts for some of the momentum transfer between the deep and shallow region (Shiono and Knight, 1996). The Figure also shows some helical secondary flows in the longitudinal streamwise direction. These cause perturbations in any lateral distribution of boundary shear stress. Secondary flows are usually directed inwards towards channel corners and outwards at re-entrant corners. The combined effect of both vertical structures and turbulence on boundary shear stress are discussed further and given in Shiono and Knight (1996).

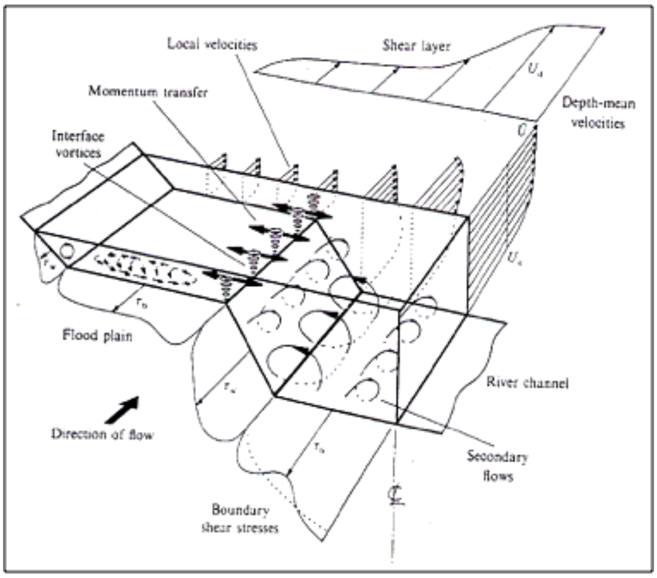
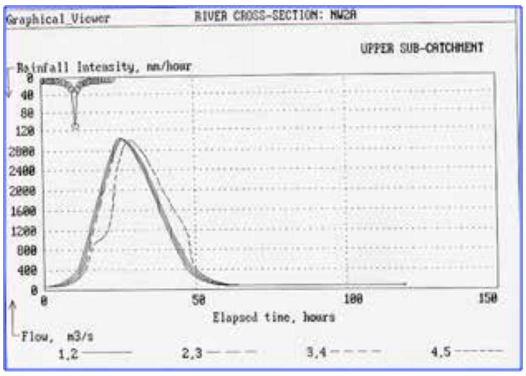


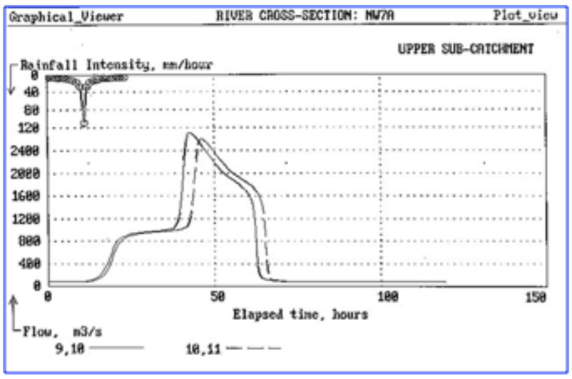
Figure 41: Hydraulic parameters associated with overbank flow (after Shiono and Knight, 1996)

Because of the momentum transfer between the main channel and the floodplains, in overbank flow the resistance to the flow varies with depth. At slightly above bankfull flow, flow resistance started to increase to a certain depth and decreases again (Shiono and Knight, 1996). This shows that in flood mitigation works there is an optimum water level to be designed for maximum flood attenuation. This water level can be determined from river modeling works. The Figure also illustrated that in overbank flows the river system not only behave as a conveyance but also as a function of storage. Again, in flood mitigation works, or river restoration works, it is advisable to include the storage in the design, hence a two stage channel (Roseli, 2004b). Based on studies by the author (Roseli, 1999) it is recommended that to get maximum attenuation (maximum reduction of peak outflow discharges) the design water level should be in the transition zone between inbank and overbank flow).

In order to understand further how to obtained maximum attenuation, Roseli, 1999 carried a study on the combination of using narrow (trapezoidal-section) with compound channel in a river ecosystem by varying the length of the compound channel. Figure 42a and 42b shows the plotted graphs.



(a)



(b)

Figure 42: Combining narrow (trapezoidal-section)/wide compound channel: the downstream hydrographs (after Roseli, 1999)

Comparing Figure 42a for 20% wide channel with Figure 42b for 70% wide channel show that more attenuation in Figure 42b. This mean introducing wide/longer floodplains can be an effective way of reducing flow, hence flood risk downstream.

Studies on some of the rivers in the world in its natural ecosystem have shown that the minor system return periods i.e. for flow in the main channel is around 1.5 – 2.0 years. Figure 43 showed typical sections and various water profiles with return periods in an unobstructed reach of river valley (Chow, et al., 1988: Original source Waananen, et al., 1977). As shown in the Figure, the main channel and the floodplains are both integral parts of the natural conveyance of a river. The floodplains carries flow in excess of the channel capacity and the greater the discharge, the further the extent of flow over the floodplains. The Figure suggested that we can design the minor system water level, say to about 5 years return period and beyond that above the bankfull flow.

The river works design consideration used is not only for rivers with adequate conveyance capabilities in the main channel and overbank flow but also as storage in the overbank flow condition which would reduce the time of peak of the peak outflow and the peak outflow. This concept should be practice in river engineering works as it allows for controlling the flow at source and reduces the risk of flooding downstream. Rivers as far as possible should be maintained in their natural states. Much of the explanation is given in DID (2000). These Figures also showed that the minor system return period design is to be contained in the main channel, while the floodplains will take care of the major system return period (Roseli, 2008). It shows the important of floodplains in river engineering works.

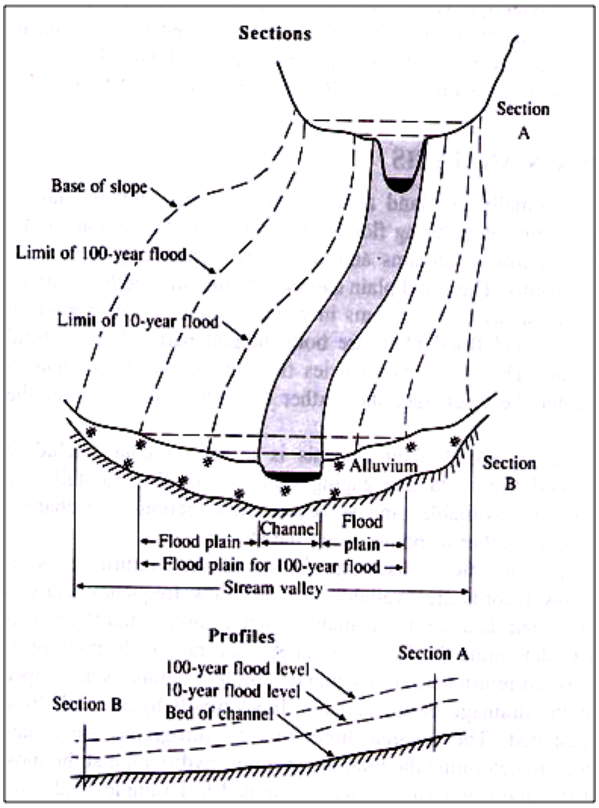


Figure 43: Typical sections and profiles in an unobstructed reach of a river valley (afterWeinmann, et al., 1977, Chow, et al., 1988)

5.4 Water Balance Equation

A water balance equation can be used to describe the flow of water in and out of a system. Water balance can be referred to the ways in which an organism maintains water in dry or hot conditions. It is often discussed in reference to plants which have a variety of water retention mechanisms.

A general water balance equation is:

$$P = R + E + \Delta S \qquad (3)$$

where,

P is precipitation; R is streamflow; E is evapotranspiration, and ΔS is the change in storage (in soil or the bedrock / ground water)

A water balance can be used to help manage water supply and predict where there may be water shortages. It is also used in irrigation, runoff assessment such as through the rainfall- runoff model flood control and pollution control.

The water balance equation (the storage equation) of interest is given in Equation (4) in the application of storage routing for optimum attenuation and storage. To determine the outflow hydrograph from the inflow hydrograph requires the application of the continuity equation. The rate of change of storage is given by (Bedient, Huber, and Vieux, 2013).

$$dS/dt = I - O \qquad (4)$$

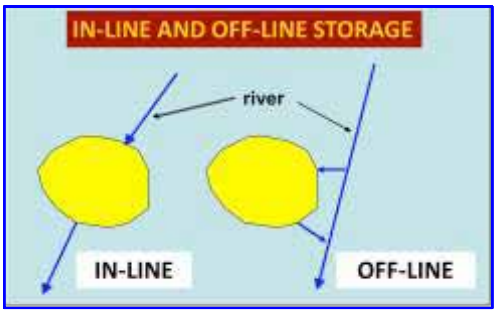
where,

I - inflow rate (m^3/s); O - outflow rate (m^3/s); S - storage (m^3); t - time (s)

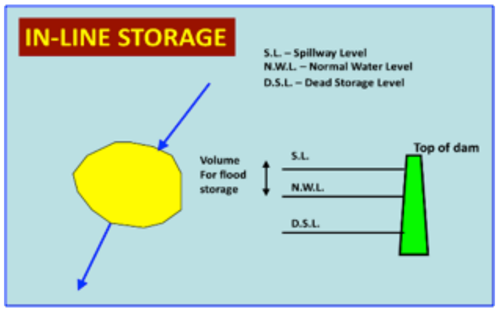
A simple water balance model is shown in Figure 44. In flood mitigation works involving rivers the rate of change of storage with respect to time is more important than storage alone especially if included in-lined and off-line ponds. Figure 45 shows sketches of in-lined and off-lined ponds. It is advisable that the control point to be at the outlet instead of inlet because to let in more discharge (not more storage) to be regulated by the water balance equation. Besides the peak outflow discharge can be regulated to control the amount of flow downstream back to the river. If the designed intake level too high to cater for 'storage' there could be backwater effect, increase in water level that could cause overflow of water upstream.

Figure 46 showing storage routing graphs. The inflow and outflow hydrographs are shown in Figure 46(a). The stored volume changes the hydrograph causing the flood peak to attenuated and delayed. Water is either being stored on released (Figure 46(b)).

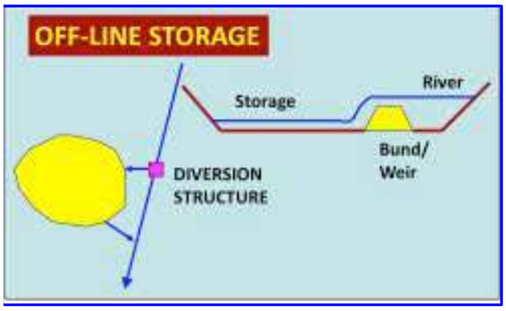
Figure 44: Balancing between storage, inflow and outflow



(a)



(b)



(c)

Figure 45: Retarding basin and regulated storage

The storage volume, *S*, is the integral of the (*I* - *O*) versus *t* curve, since

$$S = \int ((I - O)dt$$

Three cases to consider,

a. I > O, dS/dt > 0 water being stored (0 < t < *t*1)

b. I = O, dS/dt = 0 maximum storage at time ti

c. I < O, dS/dt < 0 water being released (*t*1 < *t* < *t*2)

If *t*2 is the duration of the event during which the inflow and outflow exceed zero, then for 0 < *t* < *t*2 there must be an overall mass balance.

$$\int I\,dt - \int O\,dt = \int dS = 0 \qquad (6)$$

The volumes stored equals the volume released and implies that the two areas in Figure 46(b) should be equal. The peak outflow occurs at time *t*1, where the *I* and *O* graphs intersect in Figure 46(a). This is the same at which the storage reaches a maximum, S_{max}, i.e.

$$\frac{dS}{dt} = 0$$

The peak outflow occurs at maximum storage is because O is uniquely related to S (or level, Z). Illustrated in Figures 46(c) - (f). The storage volume, S is usually plotted against elevation, Z, using contoured plan areas and the relationship

$$S = A\Delta z \qquad (7)$$

where,

A - *plan area*

See Figure 49(d). Thus, for a given value of S (marked x) the elevation Z (marked □) is known. From Figure 49(c) the time at which the value x occurs is known. Figure 46(d) translates the *S* vs. *t* relationship in Figure 46(c) into the *Z* vs. *t* relationship in Figure 46(f). Finally since the *O* vs. *Z* relationship is known, Figure 46(d) and 46(e) can be combined to give an *O* vs. *S* relationship.

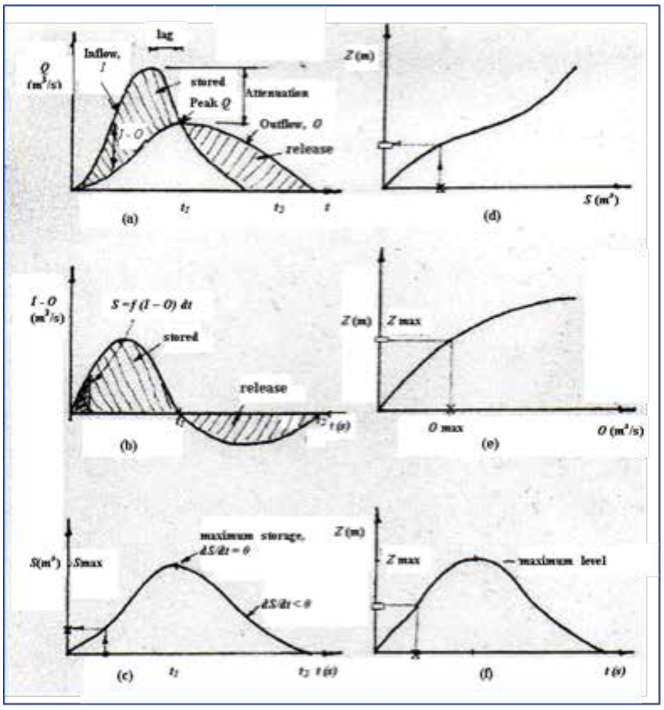


Figure 46: Storage routing (after Knight, 1995: Roseli, 2008, 2015)

6. Examples of Projects with Potential Detrimental Impacts to the Natural River Ecosystem

There are many river projects constructed in a manner which may degrade biodiversity and ecosystem, and this would ultimately deprive human-being from sources of clean, fresh surface water.

What will happen when projects implemented do not include enhancement of natural river ecosystem, biodiversity, ecology, ecohydrology in river restoration works, river cleaning, and improvement in water quality, river of life, stormwater management, flood mitigation and control. Can the output, outcome and target be met?

6.1 Case 1: River Cleaning and Improvement of River Water Quality

This project relied heavily on several large water pollution treatment plant (WPTPs), hundreds of gross pollutant trap (GPTs), concrete outlet drains, riverbanks stabilization using geotextiles, wire-mesh and hydro-seeding of grass. The project targeted to obtain certain water quality index after several years of completion.

The WPTP uses multi bed bio-filter (MBB) treatment system with cultured bacteria from the river to 'eat' the organic matter does improving the quality of the release river water downstream. If the river water is dirty then the bacteria will not be able to multiply and 'eat' the organic matter. It needs certain pH in the range of 5 to 9 for the bacteria to 'work' effectively. The bacteria also need a calculated retention time.

The main functions of GPTs constructed at drains are to trap solid wastes, sludge, oil and grease from going into rivers. The concrete outlet drains are built to discharge water effectively from residential area, workshops, food stalls, small industries, etc. effectively. Figure 47 shows the condition of one of the tributaries after project implementation.

Figure 47: Condition one of the tributary after project implementation

After project implementation, the river was observed to be in a higher state of pollution with sights of solid waste, oil and grease, black and stagnant water, damaged ecosystem, diminished water sources.

This river had previously been in a natural state with clean water. However, with the justification of "stormwater management", it had been turned into U-shape concrete channel in the 90's. With this development, the river also became more polluted with domestic waste, resulting in the river water becoming stagnant. Occasionally, during heavy rainfall, the river water overtops its banks.

This project (Case 1) was carried out to improve the river water quality and bring 'life' to the river system. However nothing was done to restore the natural river ecosystem. The many GPTs constructed, instead of making the river cleaner although they manage to trap some of the gross solid wastes, the river become much dirtier because it causes leachate to flow to the river. It also increases concentration of dirty water flowing to the river. This type of GPT has been shown in many other projects not suitable to be used. Maintenance is difficult because it need crane and heavy machinery to lift the cover and costly too. Bring danger to the workers since for the big one (Figure 48), one of the workers need to go down to guide the cage in bringing up the solid waste.

Figure 48: Operation and maintenance of one GPT

Leachate is seen to flow out to the river. Sediment, oil and grease traps have not been built. It can be seen that a lot of solid waste still floating in the river. The river water becomes oily and blackish. At the downstream of this tributary river, a floating rubbish trap had been installed. The rubbish trapped seems to have hindered further the passage of the river water resulted in more stagnant water. This rubbish trap needs modification. The rubbish could also be channelled to be collected offline.

A huge water quality treatment structure has been built near the tributary river mouth to divert the water for treatment by the structure before releasing it back to join the main river. However, only a small percentage is able to flow to the structure. Most of the water will enter the main river flow without treatment. Some rubbish also got trapped at the inlet of the structure, does hindering further water intake for treatment.

It was observed also only a small percentage of river water is able to be diverted for treatment by other WPTPs. In fact it was told that water did not enter one of the WPTP at all even after heavy rain down pour during the site visit. Figure 49 shows example of WPTP. This indicated that huge structure like WPTPs is not the answer to improve river water quality. Rather, enhancement of river health ecosystem and technique like ecohydrology approach would provide the right direction for addressing these issues.

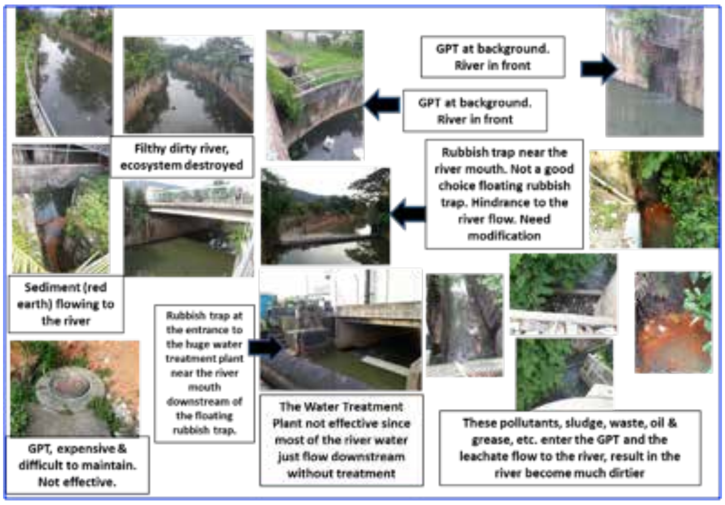
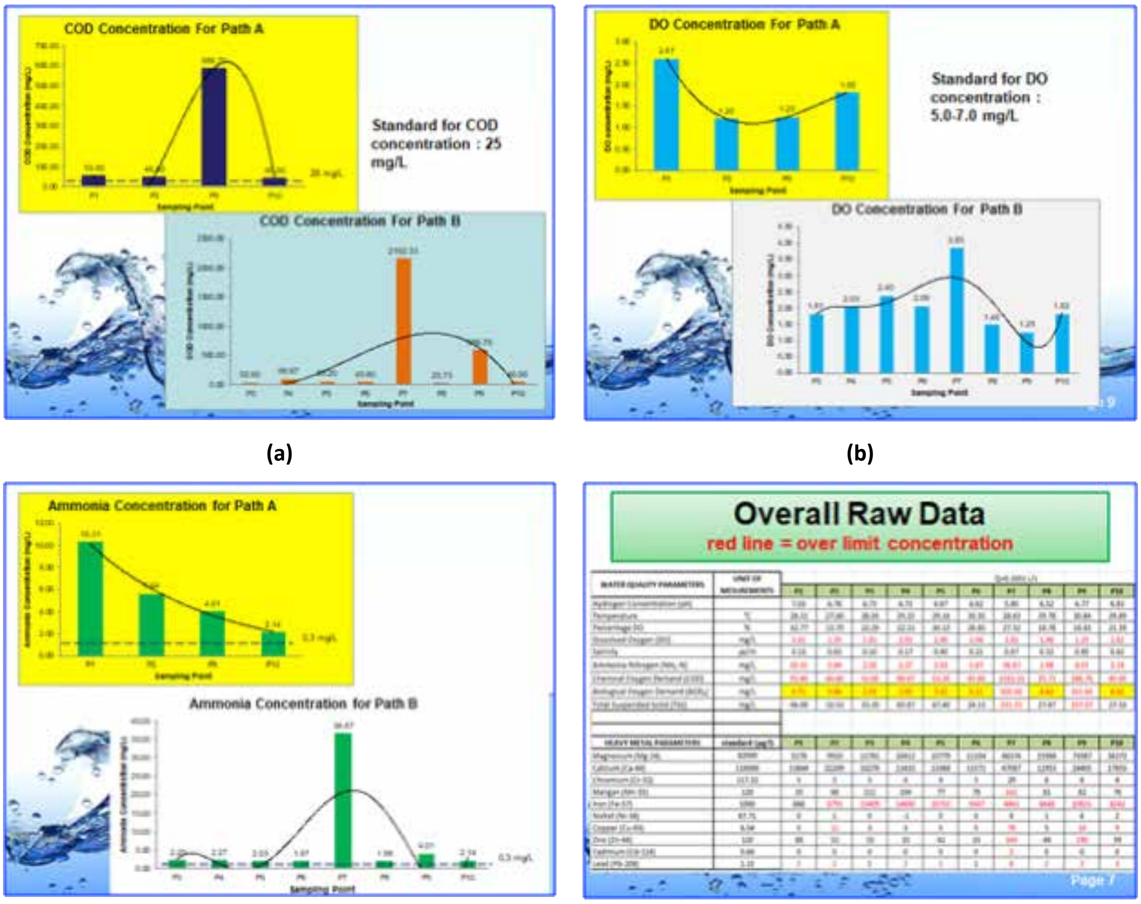


Figure 49: Example of WPTPs in the project

6.2 Case 2: River Pollution and Water Quality Improvement

The natural river was constructed with concrete-lined channel by an authority. Such development arguably would have saved maintenance cost including cutting of grass and removing tree branches falling in the river. However the action leads to losses natural ecosystem and source of clean water. The river are polluted from wet market discharges, leachate from small fish cracker industries, leftover colors from textile industry, waste thrown by people into the river, sludge, from workshops, etc.

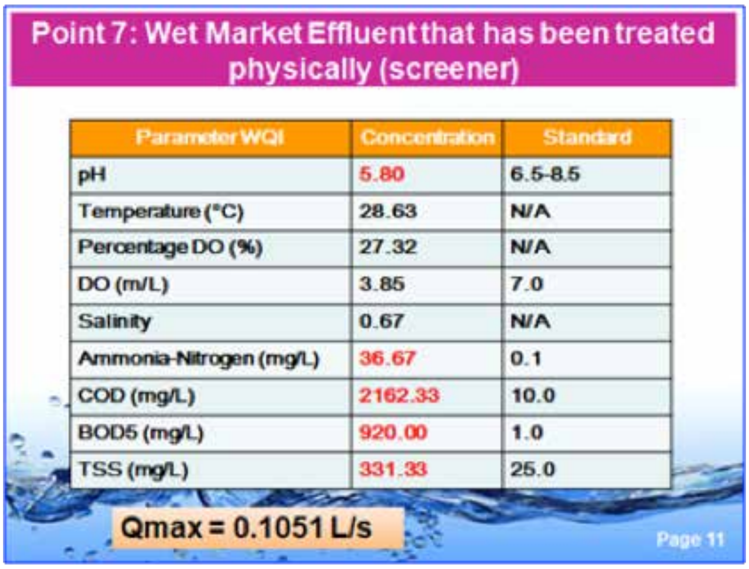
Another authority came in to handle the water pollution issues and carry out various activities to improve river water quality. The project was not focused on restoring its natural state. The river remained concrete-lined, polluted with sludge and leachate. This is evident from water parameters taken at ten (10) locations along the river (Figures 50 and 51). The worst case scenario is the discharge from GPT at Point 7 installed at one of the drain outlet from the wet market. The type of GPT is the same as Case 1 project (Section 6.1). The GPT was installed much earlier than Case 1 project. This shows the type of GPT used is not suitable to improve water quality, instead resulted in leachate problems. The values in red mean the target has not been met.



(a) (b)

(c) (d)

Figure 50: Results of water quality parameters taken along the river


Point 7: Wet Market Effluent that has been treated physically (screener)

Parameter WQI	Concentration	Standard
pH	5.80	6.5-8.5
Temperature (°C)	28.63	N/A
Percentage DO (%)	27.32	N/A
DO (m/L)	3.85	7.0
Salinity	0.67	N/A
Ammonia-Nitrogen (mg/L)	36.67	0.1
COD (mg/L)	2162.33	10.0
BOD5 (mg/L)	920.00	1.0
TSS (mg/L)	331.33	25.0

Qmax = 0.1051 L/s

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Figure 51: Bad results of water quality parameters taken from GPT installed at the wet market

6.3 Case 3: River Pollution and Water Quality Improvement

Figure 52 shows upstream of a river of about two (2) km in length. The authority improved the condition of the river keeping it in pristine condition, improving its ecosystem with green and large riparian area. This part of the river is used for recreational activities. An on-lined pond is included at its downstream part with outlet control. Thus, it regulates the flow downstream which is good for flood control.

(a) (b)

Figure 52: Part of the river in pristine condition

Figure 53 shows another part of the river managed by another authority. This part of river was concrete lined into a 'U' shape channel in the 70's for flood mitigation project except a small portion near its river mouth joining to the main river. Some of the concrete at the river banks and bed already gave way. Similar with Case 2 (section 6.2.), various activities have been carried out until 3 years back to address the pollution issues and to improve the river water quality. However, enhancement of river ecosystem has not been carried out.

(a) (b)

Figure 53: Another part of the river with damaged ecosystem

Monitoring water quality parameters have been conducted by lecturers and universities students. The results are given below (Table 3, Figure 54). The water quality index (WQI) show the site 1 (Figure 54) (upstream station) is a clean river as it being classified in Class I base on WQI index despite the location is situated in recreational area and surrounded by urbanization. Sites 2, 3, 4 and 5 (Figure 54) classification ranged from Class III – V, indicating cumulative effect of pollutants.

Using macroinvertebrate (Figure 55) as an indicator also shows similar results. This shows that projects involving river, do not damage the ecosystem.

Table3: The river sub-index parameter and WQI status: April 2012 – August 2013

	Station Location	DOSI	BOD SI	COD SI	AN SI	SS SI	pH SI	WQI	CLASS	WQ STATUS
Apr-12	Upstream	97	99	92	96	92	100	96	I	Clean
	Middle Stream 1	40	50	68	35	93	99	61	III	Slightly Polluted
	Middle Stream 2							NA		
	Downstream	0	19	44	17	79	99	38	IV	Polluted
Jun-12	Station Location	DOSI	BOD SI	COD SI	AN SI	SS SI	pH SI	WQI	CLASS	WQ STATUS
	Upstream	78	99	94	99	93	97	92	I	Clean
	Middle Stream 1	18	50	45	28	94	99	52	III	Polluted
	Middle Stream 2							NA		
	Downstream	0	4	1	23	55	99	25	V	Polluted
Aug-12	Station Location	DOSI	BOD SI	COD SI	AN SI	SS SI	pH SI	WQI	CLASS	WQ STATUS
	Upstream	91	94	96	99	89	98	94	I	Clean
	MiddleStream 1	14	53	79	0	61	99	47	IV	Polluted
	MiddleStream 2	6	15	70	0	78	99	40	IV	Polluted
	Downstream	0	12	33	0	64	98	30	IV	Polluted
Oct-12	Station Location	DOSI	BOD SI	COD SI	AN SI	SS SI	pH SI	WQI	CLASS	WQ STATUS
	Upstream	100	100	94	93	65	99	92	I	Clean
	MiddleStream 1	50	96	71	33	89	99	72	III	Slightly Polluted
	MiddleStream 2	29	95	66	19	86	99	64	III	Slightly Polluted
	Downstream	28	94	71	16	83	99	63	III	Slightly Polluted
Dec-12	Station Location	DOSI	BOD SI	COD SI	AN SI	SS SI	pH SI	WQI	CLASS	WQ STATUS
	Upstream	100	99	93	98	70	99	94	I	Clean
	MiddleStream 1	16	71	73	27	91	97	59	III	Polluted
	MiddleStream 2	16	68	67	7	86	99	54	III	Polluted
	Downstream	22	66	73	1	84	99	55	III	Polluted

	Station Location	DOSI	BOD SI	COD SI	AN SI	SS SI	pH SI	WQI	CLASS	WQ STATUS
Feb-13	Upstream	95	100	93	98	91	99	96	I	Clean
	MiddleStream 1	21	89	86	33	92	99	67	III	Slightly Polluted
	MiddleStream 2	19	52	81	7	87	99	54	III	Polluted
	Downstream	37	52	86	1	86	99	58	III	Polluted
Apr-13	Station Location	DOSI	BOD SI	COD SI	AN SI	SS SI	pH SI	WQI	CLASS	WQ STATUS
	Upstream	100	97	96	85	89	98	94	I	Clean
	MiddleStream 1	65	28	74	36	67	99	59	III	Polluted
	MiddleStream 2	61	22	61	19	85	98	55	III	Polluted
	Downstream	40	15	50	20	84	96	48	IV	Polluted
Jun-13	Station Location	DOSI	BOD SI	COD SI	AN SI	SS SI	pH SI	WQI	CLASS	WQ STATUS
	Upstream	90	96	95	92	93	98	94	I	Clean
	MiddleStream 1	12	92	91	34	89	99	66	III	Slightly Polluted
	MiddleStream 2	23	89	71	28	82	98	62	III	Slightly Polluted
	Downstream	6	86	70	19	62	99	54	III	Polluted
Aug-13	Station Location	DOSI	BOD SI	COD SI	AN SI	SS SI	pH SI	WQI	CLASS	WQ STATUS
	Upstream	93	100	94	91	89	98	94	I	Clean
	MiddleStream 1	17	43	78	0	63	100	46	IV	Polluted
	MiddleStream 2	8	44	60	0	75	99	44	IV	Polluted
	Downstream	0	4	62	0	64	99	33	IV	Polluted
Oct-13	Station Location	DOSI	BOD SI	COD SI	AN SI	SS SI	pH SI	WQI	CLASS	WQ STATUS
	Upstream	86	99	90	98	83	99	92	I	Clean
	MiddleStream 1	32	21	66	17	92	100	51	IV	Polluted
	MiddleStream 2	37	6	52	24	79	99	46	IV	Polluted
	Downstream	15	9	39	22	80	97	39	IV	Polluted
Dec-13	Station Location	DOSI	BOD SI	COD SI	AN SI	SS SI	pH SI	WQI	CLASS	WQ STATUS
	Upstream	100	99	93	98	70	99	93	I	Clean
	MiddleStream 1	16	71	73	27	91	97	59	III	Polluted
	MiddleStream 2	16	68	67	7	86	99	54	III	Polluted
	Downstream	22	66	70	1	84	99	54	III	Polluted

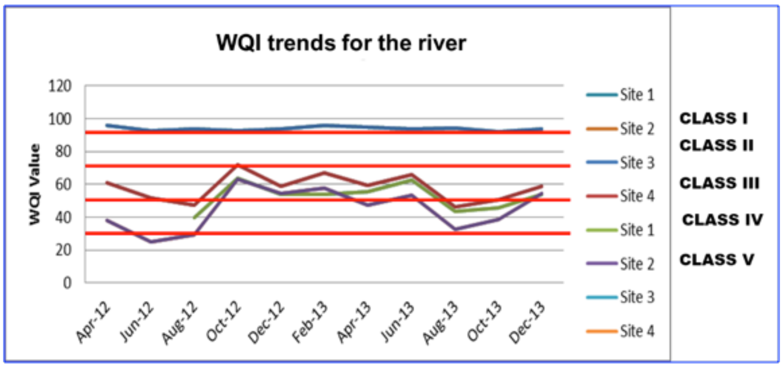
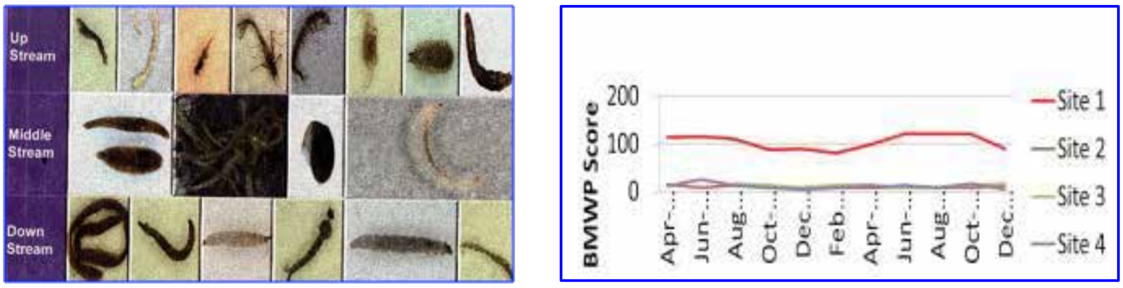


Figure 54: WQI trends for the river



(a) (b)

Figure 55: Results using macro-invertebrate

The Biological Monitoring Working Parties (BMWP) show the site 1 (upstream station) is a clean river as only sensitive taxa can be found there especially benthic macro-invertebrate family of Ephemeroptera, Tricoptera and Plecoptera; (EPT). Site 2, 3, 4 and 5 classification ranged from poor – very poor by BMWP due to pollutant and habitat degradation.

6.4 Case 4: Flood Mitigation

The river from upstream to its river mouth has been channeled and concrete-lined. The downstream section has been completely concrete-lined including the river bed. The flooding areas at that time are located upstream and downstream not at the middle section (Figure 56). During heavy rain, the water level reaches bankfull flow but no flooding. But once concrete-lined started at the upstream results in swift flow and sudden increase in water level and peak outflow discharge, resulted in the river to overflow its bank at the middle reach. The middle reach was then concrete-lined to pass the problem downstream. If the natural river ecosystem is maintained with compound channel shape there will be some storage effect which can help flood issues, underground recharge to the river during low flow, improve water quality and bring life to the river.

(a) (b)

Figure 56: Middle reach of the river

Since then the river has lost its floodplains, river reserves and riparian zone such as to commercial development at the upstream/downstream reaches.

6.5 Case 5: Flood Mitigation

The conditions after a few months completion of the project are illustrated in Figures 57 to 59.

Figure 57: Condition of the river after project completion with damaged ecosystem

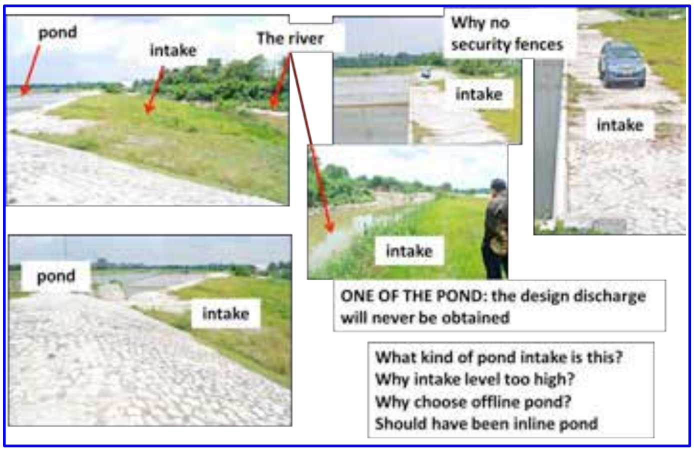


Figure 58: The problematic pond intake construction

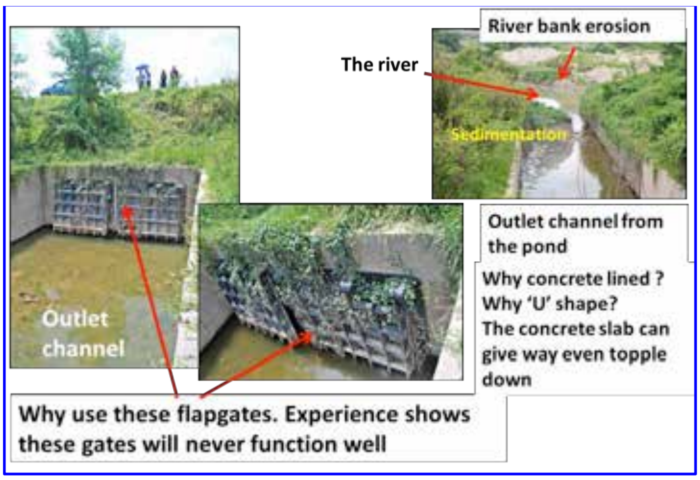


Figure 59: The problematic pond outtake

The flood mitigation project made used of two (2) existing off-lined ponds to store as much water as possible by diverting river flow and to capture local rainfall and other infrastructures without improvement to the river channel section. The flood to the surrounding area in the basin is caused by overflowing river. The first rule in any flood project is to reduce peak outflow especially during monsoon and heavy rainfall event and to maximize attenuation.

Partially this can be obtained by improving and channelization of rivers, in order to increase its carrying capacity and to obtain the design return period flow and water level. Stabilization of riverbanks is required with eco-friendly structure and vegetated materials including construction of bunds so as to reduce erosion, scouring and sedimentation of the river. Surprisingly this was not done to the project and this stretches of the river-section remain in unstable regime as shown in Figure 57.

Figure 58 shows the problematic very badly constructed pond intake. Only after few months of construction the intake was covered with undergrowth. The intake was built perpendicularly to the river flow just after the confluence of two rivers upstream. In hydraulic of flow there is an occurrence of 'leading-edge dip' at the beginning the rise of inflow hydrograph the part where the hydrograph become unstable when the intake structure is built this way. Thus, the design discharge will not be obtained. It would be better to use chute like intake or of broad crested weir which would ensure that there is no hindrance to the diverted river flow. The intake level seems to be too high. Only after heavy rainfall and high river water level can the flow be diverted. It is possible that the design was intended to maximize pond storage. The pond was designed for inlet control. It should have been designed for outlet control because the second rule is the proper used of water balance equation (basic equation, equation (4)). This way, the flow after the outlet back to the river can be regulated.

There are many unnecessary infrastructures currently built such as bitumen road, drainage drain around the large pond. The bitumen will increase impermeable area, increase runoff to the surrounding area and pond as well as result in heat island. The recommended approach would be with road aggregate and sand. For a flood mitigation project, it is recommended to focus on a natural pond ecosystem, instead of heat island for flora and fauna biodiversity. The v-shaped concrete storm drain built on outer ring of road covering the whole peripheral of the pond to capture local rainfall is not necessary. It got damage easily, became unstable, and full with earth. The fences built around the pond got rusty. There is another pond upstream used for the project. However, this project did not build fence, although fences on both sides of the inlet structure are required for safety. People, animal and cars as shown in Figure 58 can simply cross the inlet structure.

This is an off-line pond. Since the pond is near riverbank perhaps an on-line pond would be better as indicated in Sections 5.3 and 5.4. There is a need then to build a simple weir across the river downstream to regulate and control flow downstream. The excavated earth can be used to build bunds. However, the results in carrying out flood routing simulation should be compared first before making decisions.

Since the pond is just downstream after the confluence of two rivers, the recommended approach would be to divert the whole of the other river mouth to flow to the pond. The river is also known to overflow its banks. This way, the water level in the river can be reduced during heavy rainfall.

Figure 59 shows the problematic pond outtake. The type of flapgates is of little use, as they are too heavy for the flow from the pond to push through. Furthermore, as the hinges can get rusty and covered with undergrowth; these should be replaced with gates that can regulate the flow.

For the other pond upstream even during normal weather the water level can be higher than the river water level because of the two streams discharges directly to the pond. Culverts are built as the pond outlet. However flow through the culverts is hindered and stuck by debris, tree branches, plastic container, plastic bottles, etc. A floating type debris trap is necessary to divert debris for easy collection. A regulated gate perhaps using pulley system is necessary instead of using culverts.

7. Making Rivers Rich in Nature

Water edge should be as a place close to people, where people can come closer to nature. A place where natural habitats encourage flourishing. Rivers should be rich in nature and which can co-exist in harmony with human society. Efforts should be carried out to restore the natural slate of the rivers that are safe and free from disaster and at the same time enhances the beauty of landscape, and that is friendly to life forms.

The river changes its form every minute not only through the intervention of human beings but also through its own natural course. River is a habitat for many life forms (RFMCJ and DID, 1996). Difference in types of environment can be observed along the rivers from upstream to downstream section. Many different life forms make use of the different environment as their habitat. Figure 60 gives the constituents of the ecosystem.

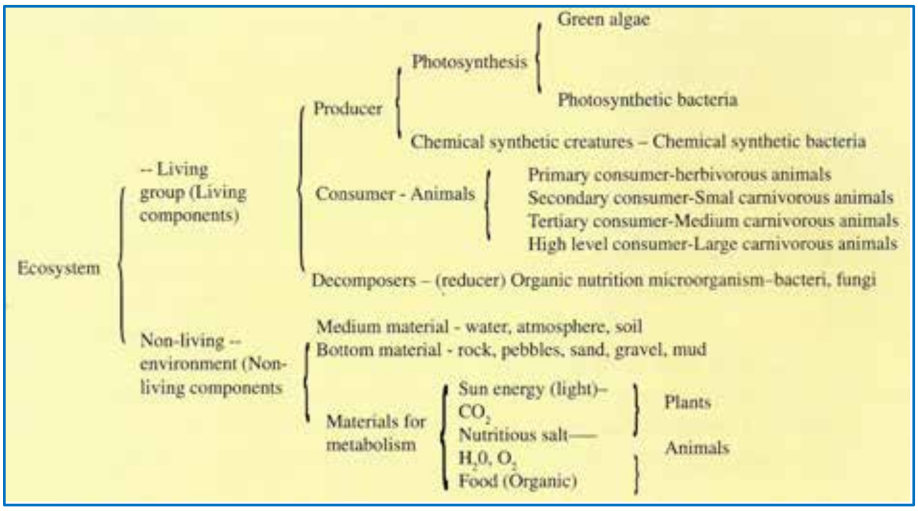


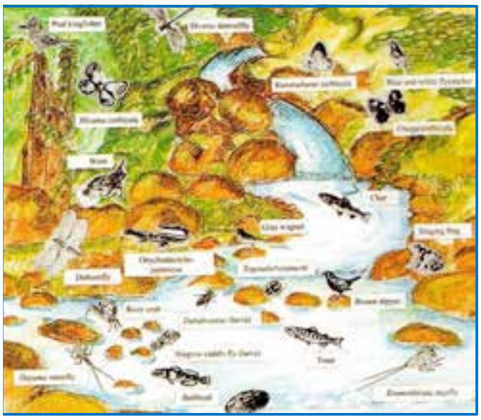
Figure 60: Constituents of a river ecosystem (after RFMCJ and DID, 1996)

7.1 Animals in Rivers (examples from Japan)

At the upper river basin, numerous aquatic insects thrive at the bottom of the river. Fishes, crabs and amphibians live in the river and feed on these aquatic insects. Birds and small animals live on the river banks so they can easily come to the river for water and food.

At the mid-section of the river basin algae grows in abundance on the surface of the stones in the shallows. This attracts aquatic insects and shellfish to live on the sides and at the bottom of the stones and deep waters. They become prey to the herbivorous, carnivorous and omnivorous types of fishes in the river. The biota here are richer compared to the upstream section of the river. At the shallow end of the riverbank, different types of birds come in search of food. There are also some birds which build their nests by the riverbank. Small reptiles and mammals can also be found in the grassy patches by the riverbank (RFMCJ and DID, 1996).

At the lower river basin, the river-bed becomes much more opened with swampy areas, flood storage pond and ditch-reed plants. The bottom of the river become muddier and where there are still water areas, aquatic plants flourish. At the bottom of the river most of the aquatic insects disappear except for those like the dragonflies, Shellfish and tubificides become more plentiful. Here, fishes feed mostly on the benthonic organisms and other fishes. Fishes that swim upstream against the current from the sea can often be seen at the river mouth. By the river, the seasonal migration of the water edge birds and water birds often stop to find food and to rest. Numerous insects and small animals live on the riverbank and many land birds can also be found. There are also reptiles and mammals which come here to prey on small birds and animals. Figures 61 and Tables 4, 5 and 6 shows animals at upstream, mid-stream and downstream of a river.



(a) Animals at upstream of a river

(b) Animals at mid-stream of a river

(c) Animals at downstream of a river

Figure 61: Animals at a river ecosystem (examples from Japan) (after RFMCJ and DID, 1996)

Table 4: Animals at upstream of a river (examples from Japan) (RFMCJ and DID, 1996)

In the water			At the water's edge		Woods on the river bank	
Insects	Fishes	Others	Birds	Others	Insects	Birds
Larva *Dabidosanae* *Kurosanae* Diverse damselfly *Oyama* stonefly *Higenagakawa* caddis fly *Ningyo* caddis fly *Shirotanigawa* mayfly *Erumonhirata* mayfly Dobsonfly Larva, Pupa *Sawadamawe* beetle *Kiboshigeshi* beetle *Marugamushi* *Togenabebutamushi*	Char Trout *Gerres oyena* *Moroco steindachneri* Dace *Zacco temminckii* *Cobitis biwae* Bullhead	(Plathelminthes) Planaria (Crustacea) River crab (Shellfish) Douglas Freshwater mussel	Brown dipper Pied kingfisher Gray wagtail Ruddy kingfisher Kingfisher	(Amphibian) Singing frog Onychodactylus japonicus	*Miyama* corbicula *Karatsubame* Corbicula *Onaga* Corbicula	Wren Blue-and-white flycatcher

Table 5: Animals at mid-stream of a river (examples from Japan) (RFMCJ and DID, 1996)

In the water			At the water's edge		On the river plain		
Insects	Fishes	Others	Birds	Others	Insects	Birds	Others
Larva *Kiirosanae* *Kooni* dragonfly *Koyama* dragonfly *Kamimura* stonefly *Higenagakawa* caddis fly *Urumashima* caddis fly *Mon* mayfly *Akamadara* mayfly Luciola cruciata **Larva, Pupa** *Ruisutsubu* beetle *Kiberimame* beetle *Hirotadoromushi*	Zacco temminckii Dace Sweetfish Zacco platypus Gobius similis Cobitis biwae Catfish Eel *Abbottina rivulans* *Pseudogobio esocinus* *Itomoroko* *Acheilognathus lanceolata*	(**Shellfish**) Marsh snail Lymnaeid *Corbicula leana* Matsukasagai Malta spiral shellfish (**Crustacea**) *Mogusu crab* *Saji* prawn Clark's crayfish (**Hirudinea**) *Hirata* leech (**Amphibian**) Singing frog (**Aves**) Spotbill duck Little grebe	Kingfisher Japanese wagtail Little tern *Charadrius placidus* Little plover Little egret Green-backed heron	(**Amphibian**) Japanese true frog (Mammal) Harvest mouse	*Komarasaki* *Tsubame* corbicula *Beni* corbicula *Tsumagurokicho* *Ginichimonjiseseri* Long horned grasshopper *Tonosama* grasshopper *Kawaragomimushi* *Nagakogane* spider *Kogane* spider	Skylark Fan tail warbler Swallow	(**Amphibian**) Japanese true frog (**Reptiles**) Japanese lizard Lizard (**Mammals**) *Apodemus speciosus* Japanese field vole

Table 6: Animals at downstream of a river (examples from Japan) (RFMCJ and DID, 1996)

In the water				At the water edge		On the river plain			On the ditch reed plain	
Insect	Fish	Birds	Others	Birds	Others	Insect	Birds	Others	Insect	Others
Larva *Onagasane* *Yamasanae* *Sesajasarika* *Ko* mayfly *Mizumeiga*	Carp *Pseudogobio esocinus* Silver crucian carp Golden crucian carp *Pseudorasbora parva* Catfish *Gnathopogon elongatus* Dusky tripletooth *Tridentiger obscurus* Mosquito fish *Abbottina rivularis* *Lottus Kazika* **Brackish water basin** *Fugu niphobles* globefish Gizzard shad Black porgy Striped mullet Sea bass	Spot-bill duck Little grebe Mallard Teal Widgeon Pintail Tufted duck Herring gull Black-headed gull	(**Oligochaeta**) Tubificid (**Shellfish**) *Himemonara* shell *Ishimaki* shell *Hiramakimizumai aimai* *Sokomaki* shell *Dobu* shell *Yamatoshijimi* (**Crustacea**) *Mokuzu* crab *Akate* crab Grapsoid crab Clark's crayfish Prawn (**Amphibian**) Singing frog (**Reptiles**) *geoclemys reevesii*	Night heron Little egret Large egret Little plover Kentish plover Pied wagtail Moorhen *Saji prawn*	Japanese true frog Harvest mouse	*Tonosama* grasshopper *Kawara* grasshopper *Tsumagurokicho* *Komarasaki* *Marukubigomimushi* Little tiger beetle	Fan-tail warbler Siberian meadow bunting Black eared kite	(**Mammals**) *pipistrellus abramus* Harvest mouse Brown rat Weasel	*Gin* dragonfly *Kubikirigisu* *Kobaneinago* *Kurnito* dragonfly	(**Crustacea**) *Ashihara crab* (**Aves**) Little Chinese bittern Great reed warbler

7.2 Rivers Rich in Nature in Asia and the Pacific Region

Environmental problems have emerged threatening social problems. It is necessary to acknowledge that the co-existence between nature and human beings is both important and indispensible. Rivers need to be designed in line with nature, sustain the culture of the region and keep the characteristics of natural rivers. The construction and management of rivers demands there should be shallows, deep waters, a clear flow of water and a habitat for the thick and lustful growth of plants life, birds, fishes, insects and other species of life forms. Rivers should be enjoyable, a place to relax and to come to term with nature (RIRJ and DID, 2004).

7.2.1 IWRM for Davao River, Philippines

UNESCO IWRM Guidelines was customized based on the experience of Davao City and Davao Region through the participative engagement of all stakeholders involved in planning of the Davao Water Action Plan and drafting the resolution for the Region-wide adoption of IWRM Guidelines furthering knowledge through research and development; furthering understanding through consultations; furthering cooperation through partnerships; furthering local capacities through capability building; sustaining implementation through enabling policies, resolutions and ban of aerial spraying in Davao City (Sales, 2016; HTCKL and WRCSAP, 2016).

The island of Mindanao in Southern Philippines has eight major river basins: the Agus River basin, Cagayan de Oro River basin, Tagoloan River basin, Agusan River basin, Mindanao River basin in Cotabato, Tagum-Libuganon River basin, Buayan-Malungan River basin, and the Davao River basin. The land area of Davao City consists of these eight major river basins drains into the Davao Gulf. Watershed management is one of the thrusts of the Environmental Plan of the City. In 2007 the City Council approved the Watershed Management Code, officially upholding an integrated approach in managing the interactions among water, land, and life forms in the eight river basins. The Davao River ranks number one in almost all of key indicators such as land use, population, and socio-economic activities. Being the largest river basin, Davao River plays a key role in ensuring water for much of the remaining 44 per cent of the population and is critical for other factors including food production and other ecological services. The multi-sectoral Davao River Conservation Coordinating Committee (DRCCC) was formed in 1999 to help conserve the Davao River (UNESCO and NARBO, 2009). IWRM spiral of Davao River is shown in Figure 62.

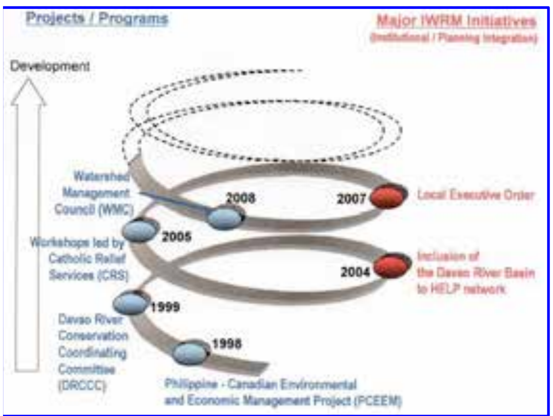


Figure 62: IWRM spiral of Davao River (after UNESCO and NARBO, 2009)

The Davao River basin is the third largest river catchment in Mindanao and is the largest of Davao City's nine principal watersheds, namely Lasang, Bunawan, Panacan, Matina, Davao, Talomo, Lipadas, and portions of Inawayan and Sibulan. Davao River ranks number seven among the largest river basins in the Philippines. Out of the nine watersheds, only the Davao- Malagos basin has been declared a protected watershed by the government on August 3, 1903, under Proclamation Number 612. This came to be known as the Malagos watershed in the third district of the city which covers Marilog District, Baguio District, Calinan District, Talomo District and Buhangin District. It has a total land area of about 235 hectares or 0.08% of the total land area of Davao City's nine watersheds. The River is the main natural reservoir of the aquifer in the city of Davao. (Make it Davao, 2013)

Davao River has a total area of 172,811 hectares, 70% of which or 113,000 hectares run through timberland, and 22% or 38,800 hectares are alienable and disposable. The River stretches 143 kilometers through a good number of streams, the main source of which originates from as far as the Salug River in San Fernando, Bukidnon and flows southward along the central part of Davao City and opens eastward towards the Gulf of Davao. Its width varies approximately from 60 to 90 meters, and the average flows within the river are estimated at 70-80 cubic meters per second near the mouth. Life along the Davao River and some of its many uses are shown in Figures 63 and 64.

(a)

(b)

(c) Aerial view of Davao River

Figure 63: Davao River
Photo credit: Jumalon, J, T (in Make it Davao, 2013)

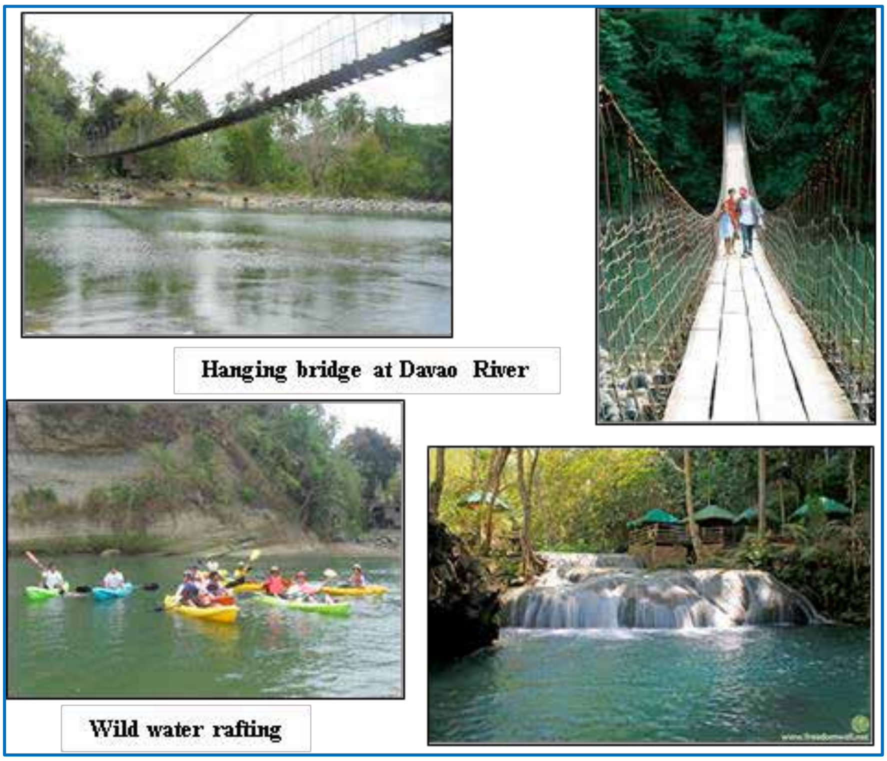


Figure 64: Parts of Davao River users
Photo credit: Jumalon, J, T (in Make it Davao, 2013)

7.2.2 IWRM for Brantas River, Indonesia

Brantas River has many functions and potency to support the human welfare. The river ecosystem possesses high biological diversity of natural herbal plants and fishery product that support economic gain of local community. There are hundreds of plants species, more than 100 macroinvertebrate species, 18 fish species and 22 waterfowl and bird species found in the river ecosystem. The river also has big potential to be developed as ecotourism site for various activities such as water sport, fishing, bird watching and camping ground. Unfortunately, the local community considers the main river function as disposal site for garbage and waste water. The waste disposal activities have resulted in river pollution and continuous to threats river's function and river's biodiversity. (riversnetwork.org, 2014)

The Brantas River basin is located in East Java province on the island of Java, Indonesia. The basin covers nine regencies or districts: Sidoarjo, Mojokerto, Malang, Blitar, Kediri, Nganjuk, Jombang, Tulungagung, Trenggalek and five urban centers or municipalities; Surabaya (capital of East Java), Mojokerto, Malang, Kediri, Blitar. Brantas River has a watershed area of about 11,800 km2 and stretches 320 km from its spring at Mt. Arjuno to the point where it branches into two rivers, the Surabaya River and the Porong River, both of which drain into the Madura Strait. The Brantas River flows clockwise with Mt. Arjuno and Mt. Kelud as its center. At the end of its southward journey, the Brantas River joins the Lesti River on the left bank and Metro River on the right bank at a point where it starts its westward flow and upstream of the Sutami multipurpose dam. The Brantas River, where it turns north-northwestward, joins with the Ngrowo River. After joining the Ngrowo River, the Brantas River flows in a northwesterly direction up to Kertosono and then turns eastward up to Mojokerto, where it branches into the Porong and Surabaya Rivers (Kikkeri and Ramu, 2004). Details of the Brantas basin are presented in Figure 65. Infrastructure in the basin is shown in Figure 66.

Figure 65: Brantas River basin index map (after Kikkeri and Ramu, 2004)

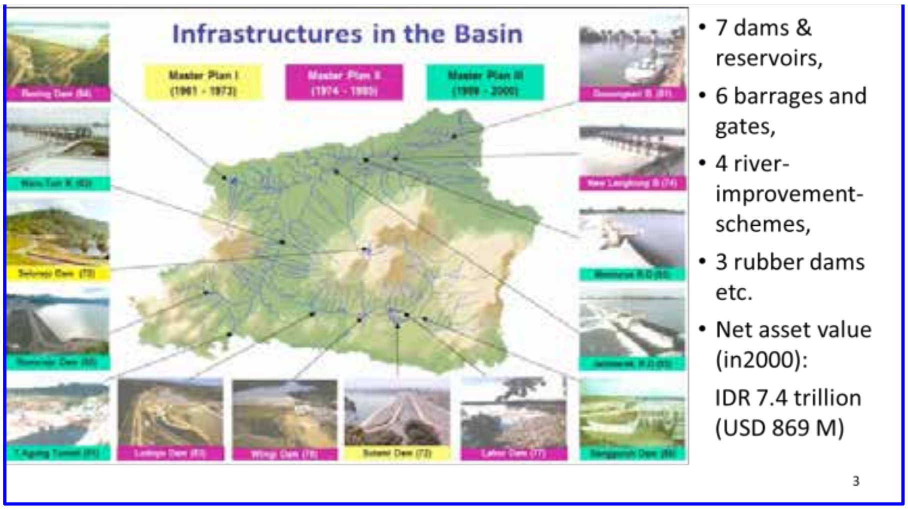


Figure 66: Infrastructure in the Brantas River basin (after Subijanto, 2015)

The development of the Brantas Basin began with a comprehensive multi-purpose project based on the concept "One River – One Plan – One Management" (Figure 67), includes multi-purpose dams and reservoirs which, among other things, improved flood control, irrigation, power generation, domestic and industrial water supply. The plan was reviewed periodically to be updated accordance to basin emerging issues and national development requirements. A special inter-provincial and cross-sectoral institution, the Brantas River Basin Development Project (BRBDP), was set up in 1961 to implement basin wide development run by central government.

BRBDP carry out development studies and the construction of major infrastructure within the basin. Following construction, their O&M activities encountered problems in obtaining funds that were required to offset their limited budget. This resulted in degradation of the water resources infrastructures. In order to obtain O&M funding, the government established the Jasa Tirta 1 Public Corporation (PJT1) in 1990 through Government Regulation No. 5/1990. Its major task is to manage water resources in the forty tributaries and rivers within the Brantas Basin as well as operate and maintain the major infrastructures. They can allocate water for independent and professional purposes. PJTI is managed by a board of directors and a supervisory board composed of central and provincial government representatives. PJTI has played an active role in developing effective coordination of water resources management among all stakeholders (UNESCO and NARBO, 2009).

Figure 67: Brantas River basin One River – One Plan – One Management (after Subijanto, 2015)

The Water Resources Management (WRM) Committee was established by the East Java Governors Degree No. 59 of 1994 as a coordinating body where all aspects of water resources management (planning, implementation, supervision, control, and funding) are decided. It includes allocating water among users in the basin and conflict prevention.

The BRBDP, which became the Public Utility Type River Basin Organization (RBO) of Brantas River Basin in 2007, the Provincial Water Resources Services (PWRS), and the PJT1 Corporation joined forces within the WRM Committee to collaborate, manage, monitor and evaluate water resources management of Brantas River. In terms of O&M works and water resources utilization, PJT1 is responsible for conducting preventive O&M works and water resources utilization within the whole basin; the Public Utility Type River Basin Organization of Brantas River Basin is responsible for conducting preventive O&M works outside the forty rivers managed by PJT1 as well as rehabilitation works in the whole basin; and the Basin Water Operation Unit under PWRS is responsible for conducting O&M works of the irrigation system. Figure 68 depicts the institutional framework for Brantas River Basin Management. The Water Resources Management (WRM) committee coordinates with all basin-wide stakeholders.

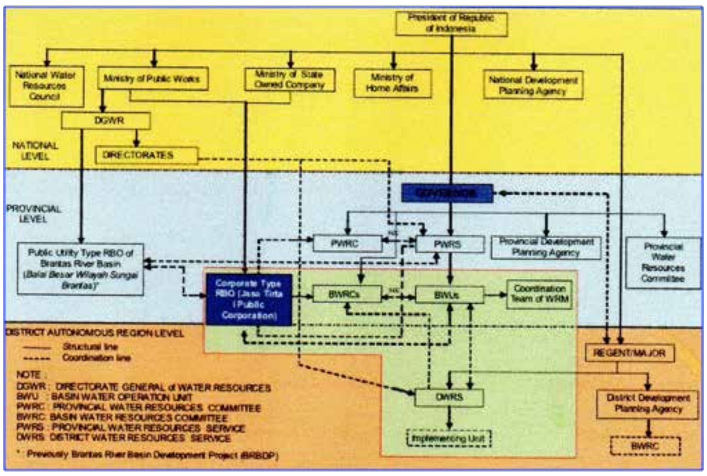


Figure 68: Institutional Framework for Brantas Basin Management (after NARBO and UNESCO, 2009)

Under the Law No. 11/1974 replaced by Law No. 7/2004 on Water Resources, the Indonesia Government has enacted the two (2) types of RBOs (Table 7)

- Public Utility RBO: It is government body, placed under supervision of the government, strong legitimacy, managed and staffed by government employees (30 RBOs - Central Government and 50 RBOs - Provincial Government).
- Corporate RBO: It is a RBO in form of corporation owned by the Government to implement part of the Government responsible in WRDM. Responsible to the Government for its activities but otherwise operating as an independent and financially autonomous legal entity (2 RBOs: PJT-I and PJT-II).

Some of Public Utility RBOs are prepared to "*quasi typed Corporate RBOs*". If in future, the financial aspect improves, they will be transformed into corporate RBOs (Subijanto, 2015).

Table 7: Two types of RBO for Brantas River basin (after Subijanto, 2015)

	Corporate Type of RBO	Public Type of RBO
Ownership	The state	The state
Governing board	Representatives of several ministries	Single ministry
Legal basis	Gov. Reg; formal registration	Ministerial decree
Operation	Based on specific bylaws; independent from the gov. system, flexible mobilization of resources	Based on specific assignment of the ministry, dependent on the government
Management	CEO-style director with high autonomy, responsible to the governing board or shareholders, taylor-made management systems, costumer focus, quick response to new challenges and opportunities	Government bureaucratic approach, mostly hierarchical in decision making, non flexible system of management, physical project focus
Staff	Employed directly, independent on capacity and HRD; own salaries and benefits system (tallent based HRM and performance based salary system)	Government employees, centralized salaries and in line to the government terms of conditions.
Budget	Prepared autonomously, approved by the Ministry, flexibility in utilization inline with general policy and rules, approved by the board	Governmental funding, approved by parliament, consistently with Gov budgeting rules, limited flexibiliy
Financing	Revenue from operation (user fees); gov. transfers; performance contracts; loans; bonds; grants	Revenue solely from governmental fundings
Responsibilities	Water services, operation and preventive maintenance, emergency maintenace, specific services related to utilization of its resources	Planning and construction of new WR infrastructures, corrective maintenance responsibilities, regulatory functions

Images of Brantas river ecosystem is shown in Figure 69.

Figure 69: Images of Brantas River ecosystem
Photo credit: google.com; images may be copyrighted

7.2.3 Examples of Nature-Rich Rivers in South Korea

The Figures 70 and 71 show examples of designing rivers rich in line with nature that ensures the sustainability of biodiversity and ecosystem. The Figures are self-explanatory.

Figures 70: Yangjae stream (after MLTM, 2010)

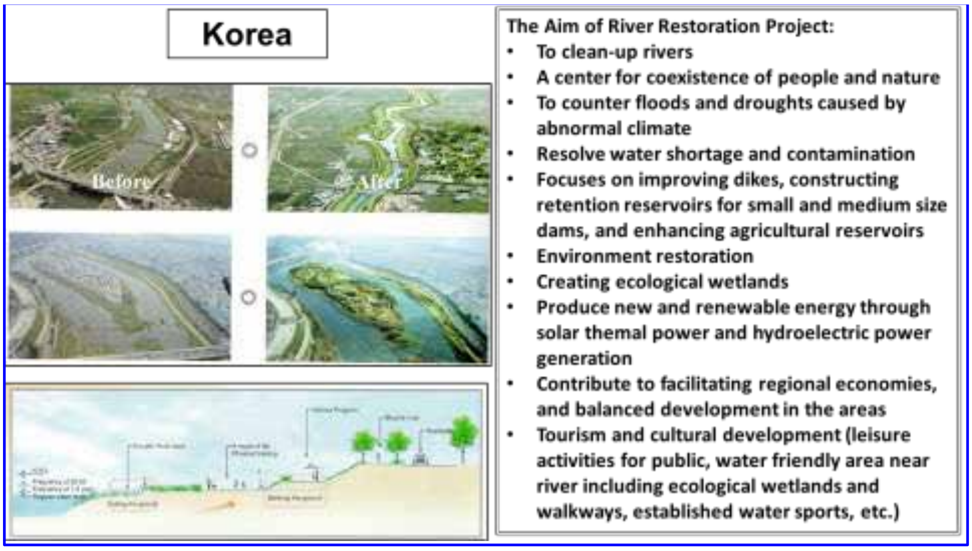
(a)

(b) (after Star2, 2017)

Figures 71: Cheong-Gye-Cheon river rich in nature

South Korea carry out projects to clean-up four (4) major rivers including Han River, Nakdong River, Geum River and Youngsan River in an effort to develop fundamental measures to counter floods and droughts caused by abnormal climate. The rivers will become a center for the coexistence of people and nature. The aim of the project and the condition of the river before and after the project are shown in Figure 72. The clean-up project is a success story in creating nature rich rivers at the same time solving counter floods and droughts.

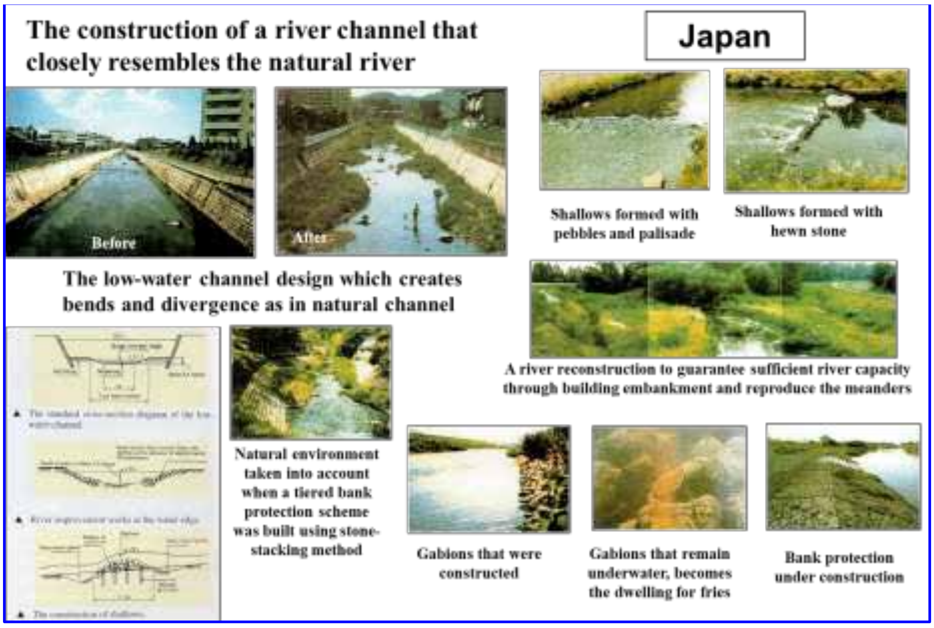
This project can be compared with project Case Study 1 in Section 6.1 that damage the river ecosystem.



Figures 72: Restoring river to its natural state to counter floods and droughts (after MLTM, 2010)

7.2.4 Examples of Nature-Rich Rivers in Japan

There are many nature rich rivers in Japan. A few of the river works carried out can be seen from RBMC (1992), RBMLIT (2007), RDBC (1988), RFMCJ and DID (1996), RIRJ and DID (2004) in the references. A few of them are shown in Figure 73.



Figures 73: Examples of river that are rich in nature (after RFMCJ and DID, 1996: RIRJ and DID, 2004)

A natural river flows in a zigzag formation. Even if the river was constructed to be straight, the meandering nature of the flow persists and in turn the flow channel meanders regardless of the straight path constructed. Due to this, shallows and deep waters are always found in rivers. In addition, the water edges of these rivers are never uniform and consist of bends. The normal-line low-water channel design which produces bends and divergence, can be applied to rivers fixed in concrete to make it look more like a natural river and encourages the formation of shallows and deep waters.

Shallows and deep waters effectively enhance the self-cleaning action of the river by drawing air into the water, causing contaminants to form sedimentation and so on. The pebbles and soil by its water edge also encourages the activity of macro-organisms (RFMCJ and DID, 1996).

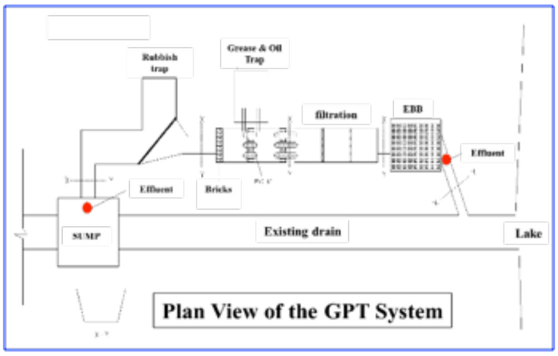
8. Some Recommendations on Rubbish Traps

Gross pollutant trap (GPT) as shown and used in Case Study 1 (Section 6.1) and the same type used in Case Study 2 (Section 6.2) may be suitable for use in some countries but not for others. Similarly, GPT may be suitable in some projects but not for others. It will be suitable if the trapping is intended to be limited to gross pollutants and solid waste. However, it is not suitable when the rubbish includes sludge, oil & grease, chemical waste, coloring materials such as dye, etc. It will not be suitable when leachate are produced and discharged to the river. River will become much dirtier, and form of life in the river will be affected as proven for the Case Studies 1 and 2. The cover for this type of GPT is very heavy. It needs machinery to lift-up for operation and maintenance work. The operation and maintenance work become unnecessarily difficult and also costly. The GPT will therefore need modification or different types of GPT should be used. The author recommends a few types as discussed below.

1. The Gross Pollutant Trap Offline IP No. 3/1

This type of GPT (Figure 74) was developed by a Professor in a university to trap solid waste, sediment, oil & grease separately offline in a GPT system for drains. Testing was carried out in the university and water is then released to a lake.

(a)



(b)

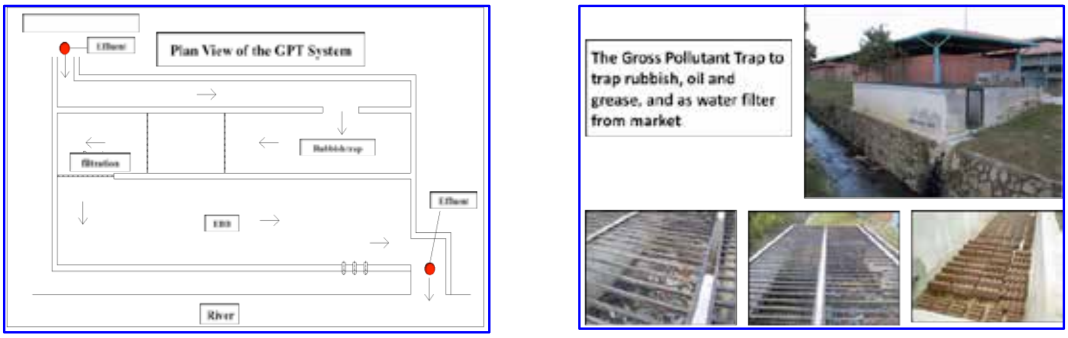
(c)

Figures 74: The Gross Pollutant Trap Offline IP No. 3/1 (after Roseli, 2004)

2. The Gross Pollutant Trap IP No. 3/2

This type of GPT (Figure 75) was developed by the same Professor in the university to treat wastewater for wet market disposal. The test side was at a wet market.

An experiment was carried out to determine the efficiency of water treatment system in treating the wastewater generated from market. The treatment system is divided into three zones: rubbish trap, filtration and eco-biological block.



(a) (b)

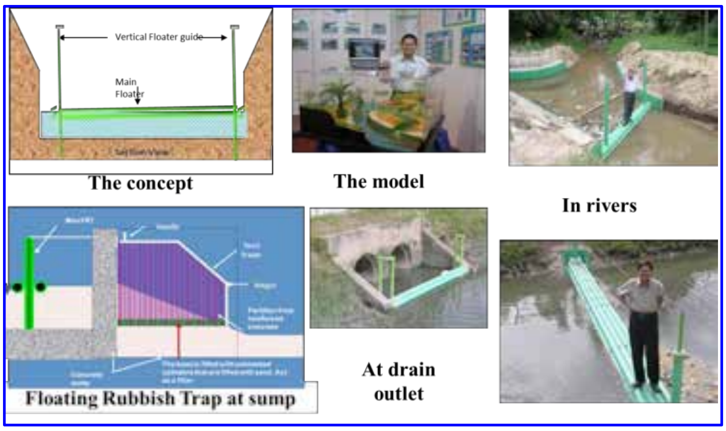
Figures 75: The Gross Pollutant Trap IP No. 3/2 (after Roseli, 2004)

3. Interlocking Modular Floating Rubbish Trapper

The interlocking Modular Floating Rubbish Trapper (MFRT) was developed by an individual to trap floating rubbish in drainage system and middle size rivers. Based on studies conducted it is estimated that 80% of the rubbish is floating. MFRT can trap effectively floating rubbish such as solid waste, oil & grease, plastic bottles, plastic & polystyrene food container, water hycine plant, leachate, etc.

The technology makes used of specially formulated UPVC pipes that can partly float and partly submerge in water, interlocking together and place at an angle to divert the rubbish to one side for easy collection. The components of this type of system can be easily joint, connected and installed. An offline collector chamber can also be provided. Other materials can also be used such as strong bamboo tied together or light weight foam concrete that has density lighter than water. It can also be constructed offline, at the end of drain, at drain sump, etc. The rubbish can also be collected offline using mechanical collector system. Another MFRT is called anti-backflow rubbish trapper (ART) suitable to be used at the end of small drain before joining monsoon drain, stream or river.

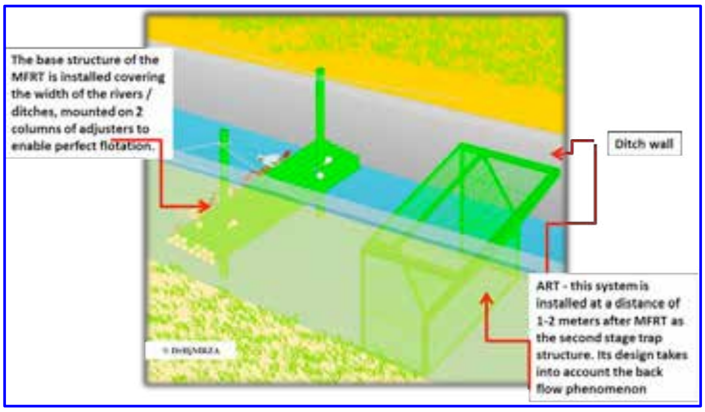
Example of MFRT used, its performance are shown from Figures 76 to 80.



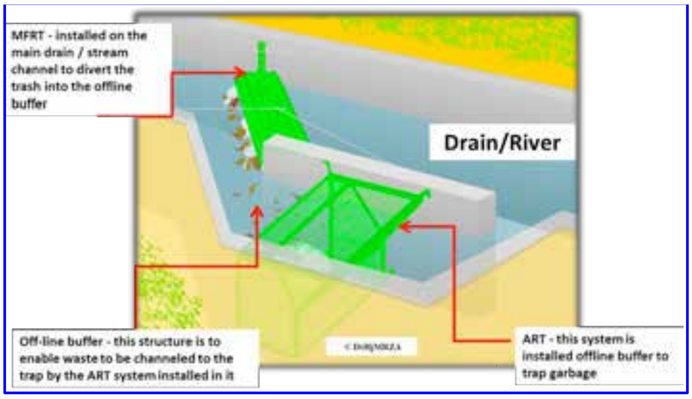
Figures 76: The interlocking modular floating rubbish trapper (MFRT) (after Roseli, 2004)

Figures 77: MFRT: Effective solid waste rubbish trapper (after Roseli, 2004)

Figures 78: MFRT: Effective in trapping floating rubbish (after Roseli, 2004)

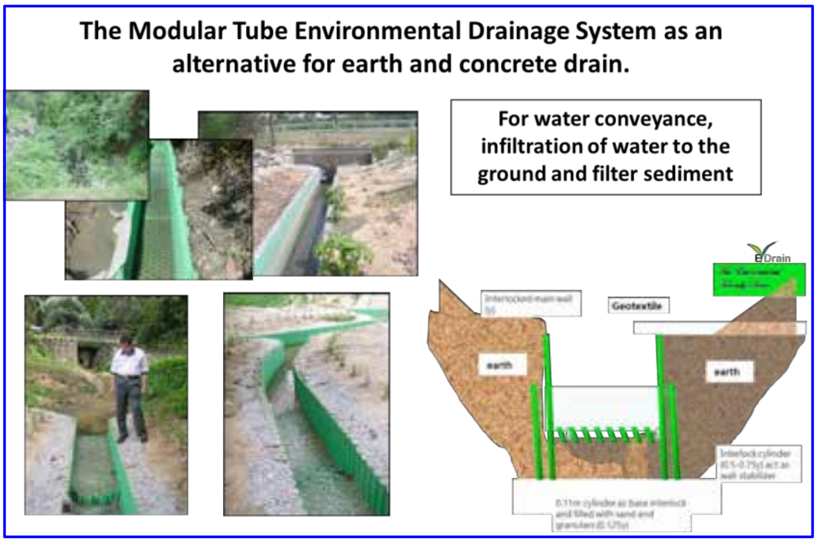


Figures 79: MFRT inline system with ART (after Roseli, 2004)



Figures 80: An inline MFRT with offline ART system (after Roseli, 2004)

The modular tube can also be used as a drain (Figure 81).



Figures 81: Modular tube as a drain (after Roseli, 2004)

9. Lessons Learnt and Remarks

- Understanding the natural river ecology, ecosystem, diversity, behavior, its morphology and hydraulics will enhance scientific knowledge, in water resources management, stormwater management ecohydrology, river restoration works, river of life project, water pollution control, flood mitigation projects and many other projects/programmes related to water.
- In any watershed management projects/river works, there should be at least 4 objectives: enhancement of biodiversity/ecosystem; water quantity control (maximize attenuation, reduced peak outflow discharge, the proper used of water balance equations); water quality control at source and in the system; related to socio- economy of the people. This integrated approach is important, as opposed to a one- objective for each project because the target most likely will not be met, as Albert Einstein said: "You cannot solve the problem with the same kind of thinking that created the problem".
- River projects must be targeted towards restoring its natural state, enhancement of the natural river ecosystem, enhancement of biodiversity, ecology, and ecohydrology, to ensure that human-being will not be deprived from sources of clean, fresh surface water and food.
- Water edge should be as a place where people can come closer to nature. A place where natural habitats encourage flourishing. Rivers should be turn into that are rich in nature and which can co-exist in harmony with human society. Attempts should be made to design or restore more natural rivers that are safe and free from disaster, enhances the beauty of the landscape, and that is friendly to life forms.
- In flood mitigation projects, knowledge of attenuation (the differences between peak inflow and peak outflow discharges), change of storage with respect to time, forces acting on the river channel, compound channel flow, inflow-outflow relationship, among others, are necessary. The two (2) basic rules are attenuation of the hydrograph and the proper use of the water balancing storage with respect to time equations.
- Sections of the natural river should be of compound channel with storage area and functions, instead of trapezoidal or 'U' shape. The river flows need to be designed for minor return period in the main channel and major return period for the second stage (floodplain section). Water level should be maintained at two-third bankfull flow for optimum water resources and aquatic life. Recommended design water for flood water level at the transition zone (between bankfull and overbank flow) is necessary in order to obtain maximum attenuation. A green belt riparian zone needs to be provided.
- The uses of proper rubbish/garbage/waste trapping system will improved stream/river water quality.
- It is not recommended to use large water treatment plants in river works for cleaning, handling pollution issues and restoring life to the river as they are expensive, difficult to operate and maintain. The focus should be to restore river to its natural state with its natural ecosystem as discussed throughout the topic.

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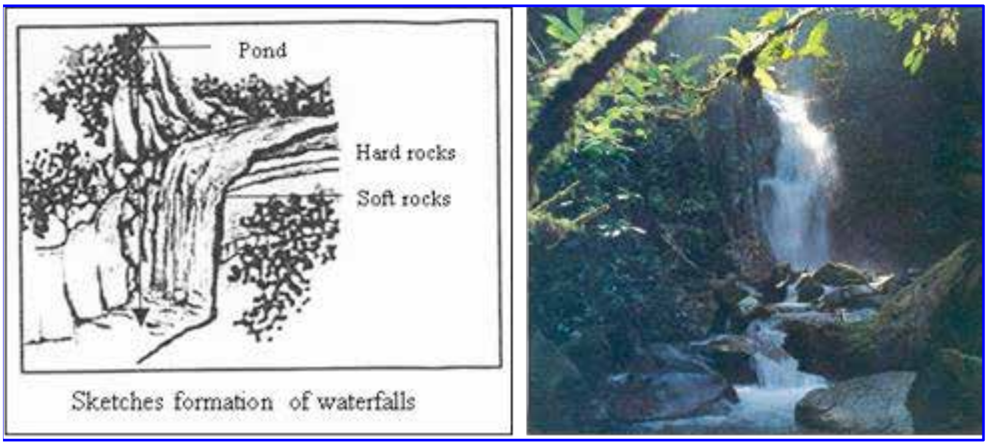
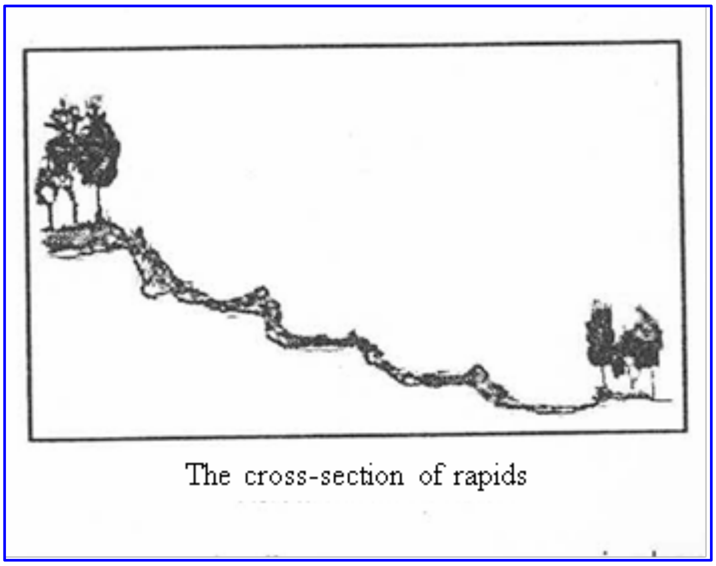
Appendix A

Characteristics and Features of Natural River

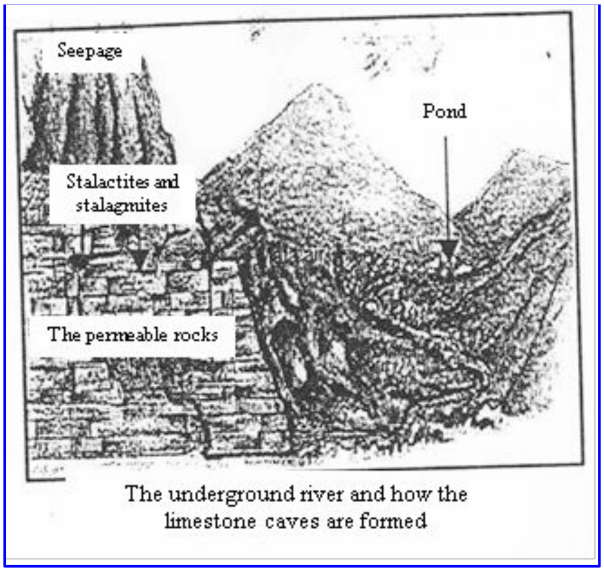
A1: Young river



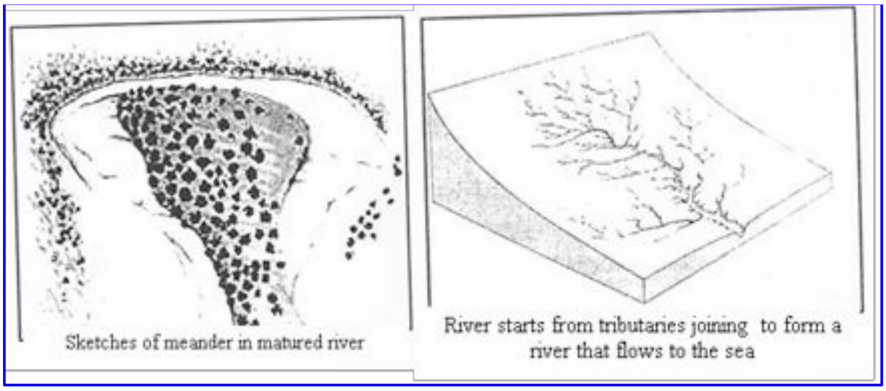
A2: Waterfall



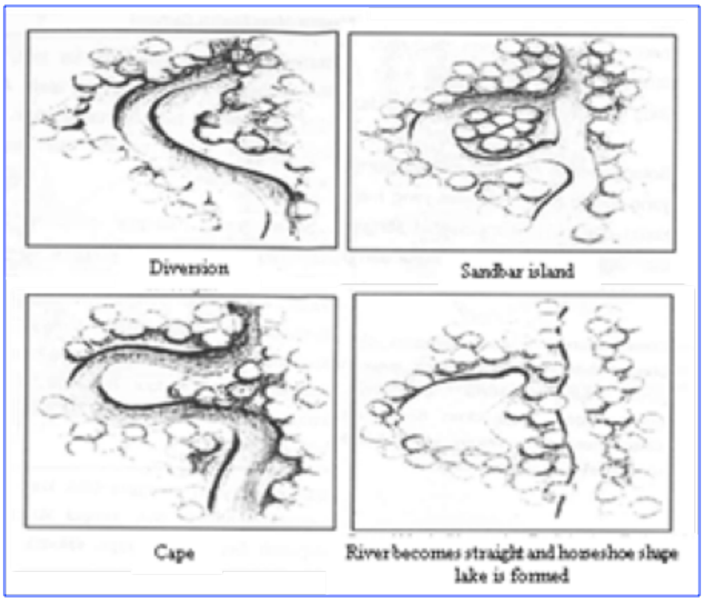
A3: Sketches of rapids



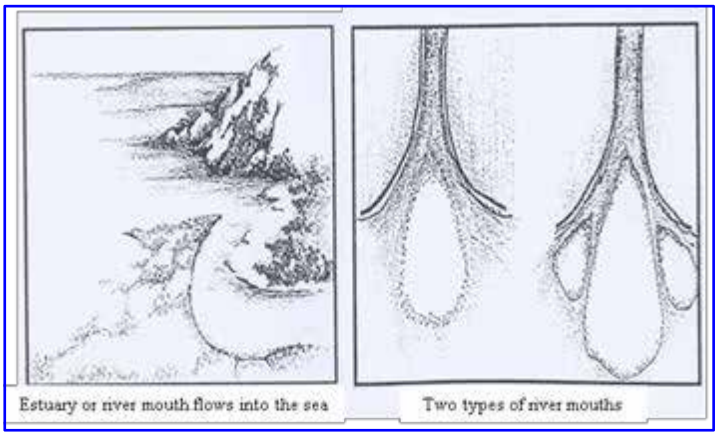
A4: Sketches of underground river



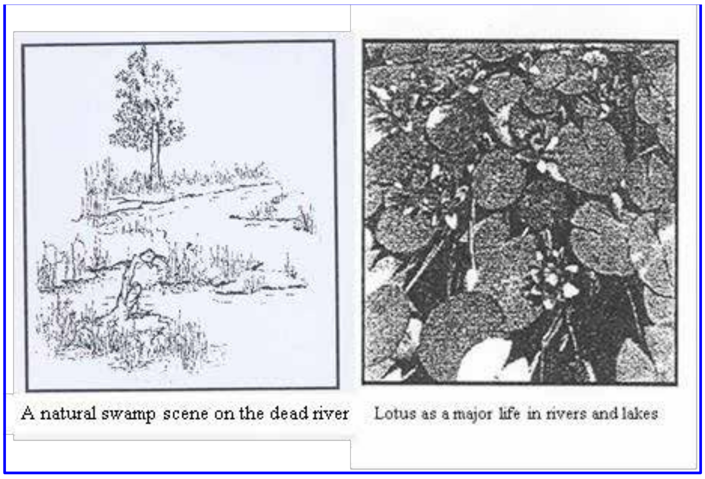
A5: Sketches of mature river



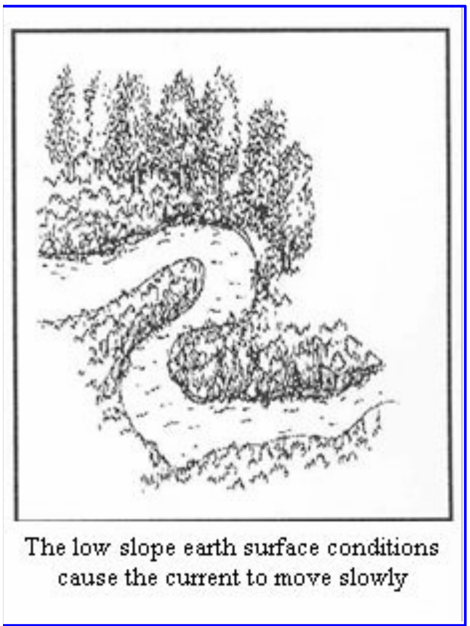
A6: Sketches of old river



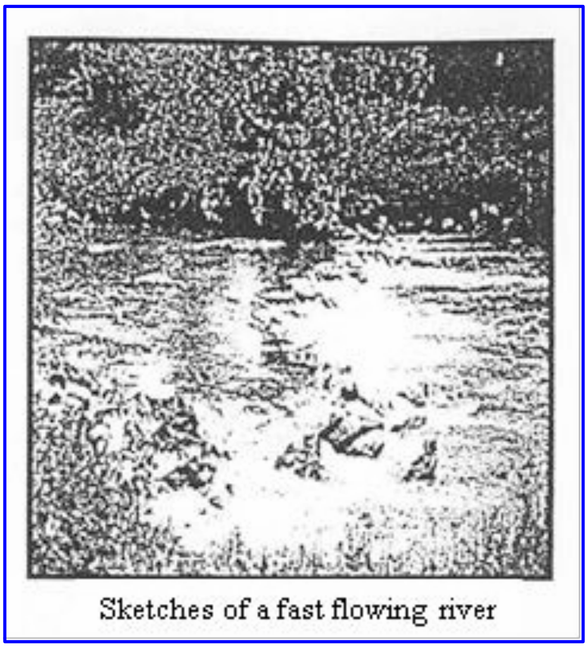
A7: Sketches of river mouth/estuary



A8: Still water



A9: Slow flowing river



A10: Fast flowing river

A11: Highlands and hilly forest area

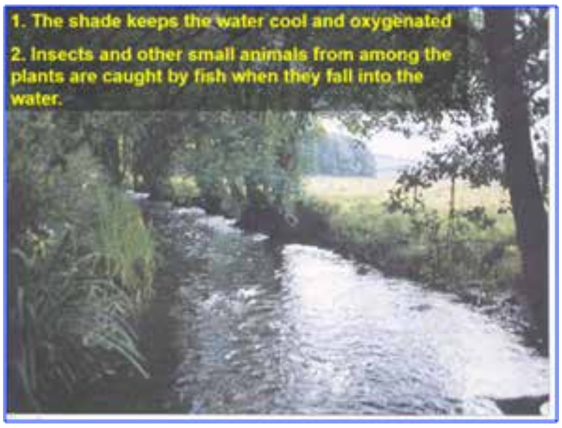
A12: Examples of Constructed Wetlands

A13: Dam

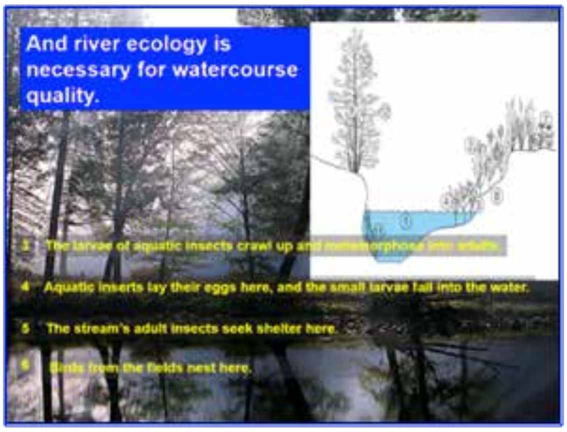
A14: Sand extraction

Appendix B

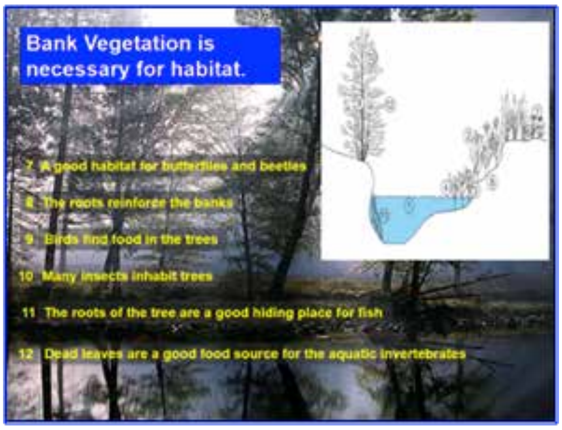
Examples the on the Importance of Natural River Ecology and Ecosystem



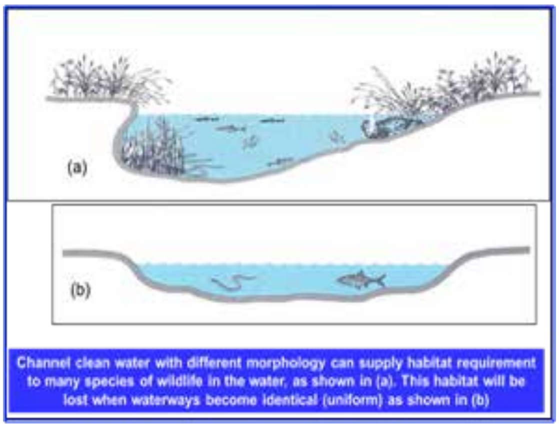
(a)



(b)

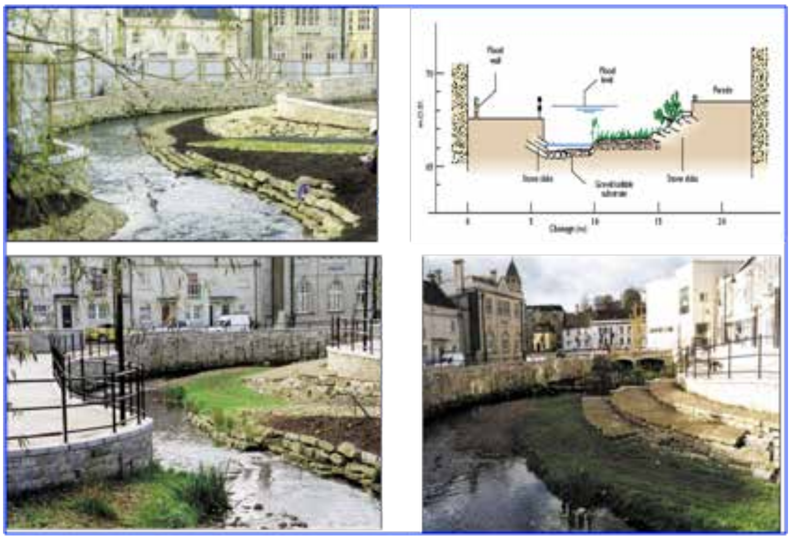


(c)

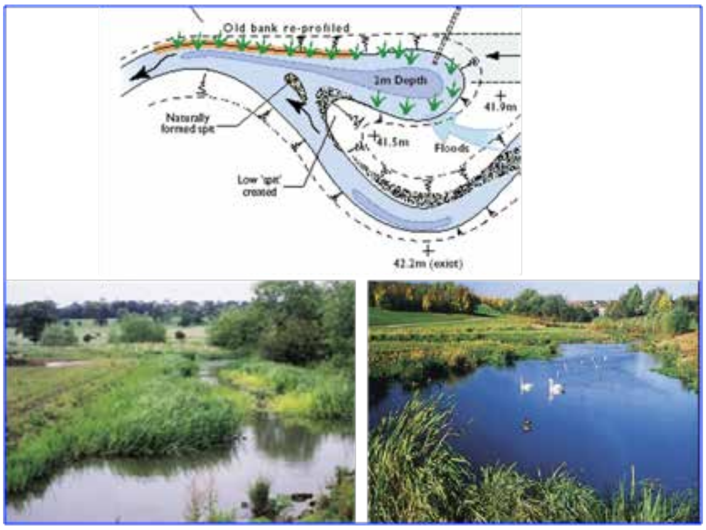


(d)

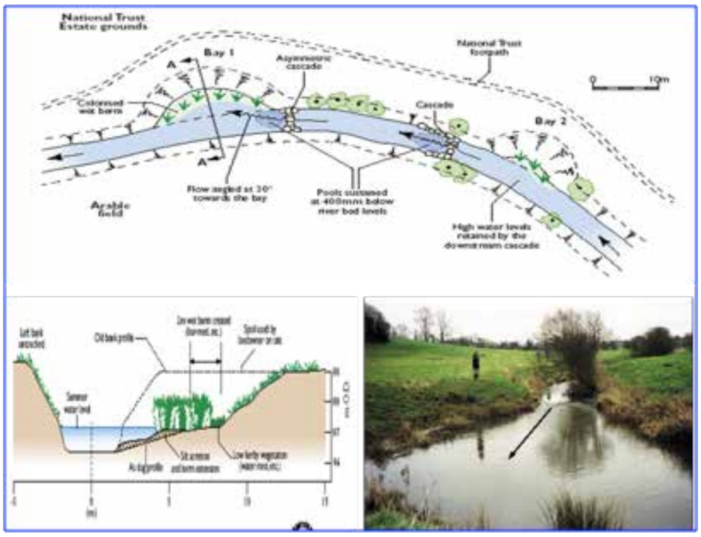
B1: River ecology for watercourse quality and habitats' requirement



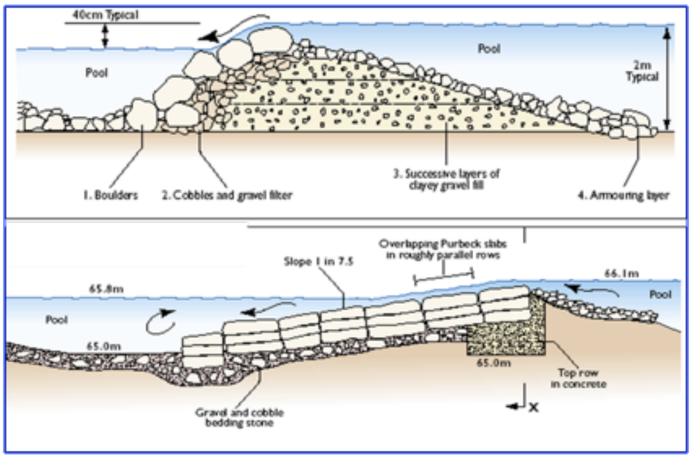
B2: River ecology in restoring meanders (after USDA, 2007)



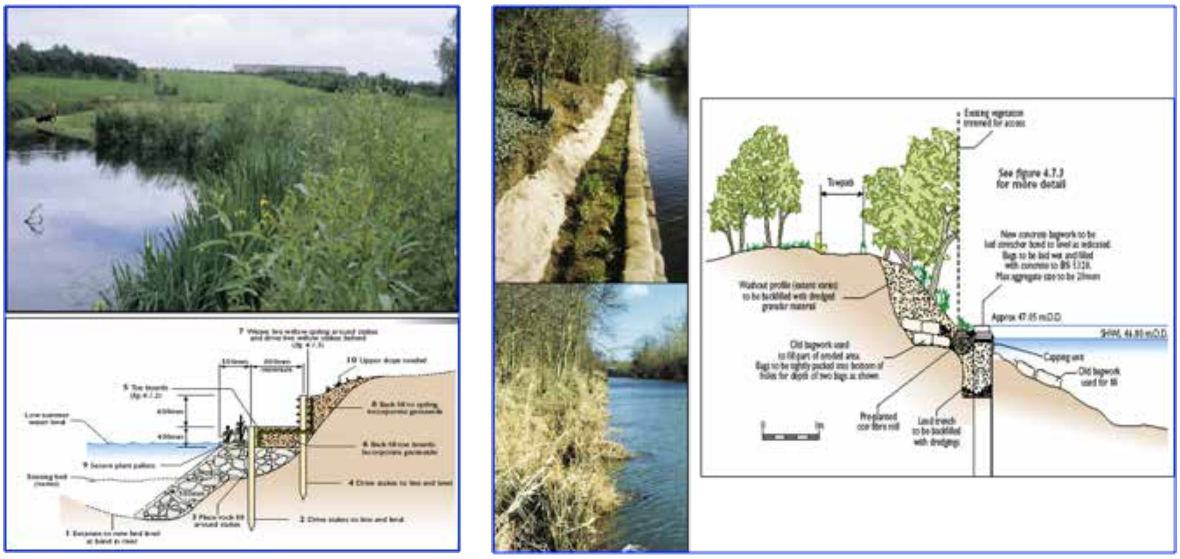
B3: River ecology in creating of backwater area (after USDA, 2007)



B4: River Ecology in creation of on-line bays (after USDA, 2007)



B5: River ecology in controlling river bed and water levels (after USDA, 2007)



(a) (b)

B6: River ecology in supporting river banks (after USDA, 2007)

Topic 3

Managing Environmental Flows for People and Healthy Aquatic Ecosystems

Mobilizing Science for Healthy Ecosystems


Tangkahan, Gunung Leuser National Park, North Sumatra, Indonesia

Topic 3

Managing Environmental Flows for People and Healthy Aquatic Ecosystems

Summary

In order to balance competing demands for water resources such as meeting human needs for freshwater provisioning services, maintenance of fisheries and biodiversity, and ecosystem function, it is critical that the society explicitly agrees on ecosystem water requirements (environmental flows). In regulated freshwater ecosystems, the optimal use of environmental flows (E-flows) will often require altered management of water infrastructure, supported by institutional arrangements. Once an E-flows regime has been identified, management of freshwater ecosystems is likely to change. In highly modified and regulated systems, this may require decommissioning of dams or mitigating and altering dam operations and other water resource infrastructure, for example, managed flow releases.

1. Introduction

1.1 River flows need to be regulated for the ecosystem, water resources, socio-economy, flora, fauna, habitats, aquatic life, and stabilization of river banks/section, etc. There is growing awareness that increased water use by humans does not only reduce the amount of water available for industrial and agriculture development but has a profound effect on aquatic ecosystems and their dependent species. At the same time, human activities have severely affected the condition of freshwater worldwide. This capacity to support biodiversity appears to be highly degraded with many freshwater species facing rapid population decline or extinction.

1.2 One of the efforts on resource-management strategy is in managing E-flows in aquatic ecosystem. In aquatic ecosystems, such as rivers, wetlands, estuaries and near-coast marine ecosystems provide a great variety of benefits to people. These include 'goods' such as clean drinking water, fish and fibre, and 'services' such as water purification, flood mitigation and recreational opportunities (Dyson, M., Bergkamp, G., & Scanlon, J., 2003). Rivers and other aquatic ecosystems need water and other inputs like sediment to stay healthy and provide benefits to people. E-flows are a critical contributor to the health of these ecosystems. The absence of E-flows puts at risk the very existence of ecosystems, people and economies.

2. The Science of E-flows-Ecosystem Relationship

2.1 The goal of E-flows is to provide a flow regime that is adequate in terms of quantity, quality and timing for sustaining the health of the rivers and other aquatic ecosystems. E-flows must be seen within the context of applying IWRM in catchments and river basins.

2.2 IWRM is a necessary framework for water resources management in considering all interactions of human with the water cycle. It promotes the coordinated development and management of water, land and related resources while enhancing the sustainability of natural ecosystem environment. Hydroecology, Ecohydrology, Ecohydraulics and E-flows are branches of science that aim to support water management through improved representation of the relationships between hydrology, habitat, biodiversity, and ecosystem function. E-flows can be considered as one of the sub-disciplines under Ecohydrology. In broader sense, E-flows refer to the water regime of a river, wetland or coastal zone necessary to maintain the biophysical components, ecological process and health of aquatic ecosystem and associated ecological goods and services.

2.3 Cases where total actual water use exceeds the difference between total water available and environmental water requirements may be referred to as cases of environmental water scarcity. Studies showed that there are basins in this world with insufficient water to meet environmental water requirements. When the ecosystem's water requirements are taken into account, more basins show a higher degree of water stress. (Smakhtin, V., Revenga, C., Doll, P., 2004)

3. E-flows in Healthy Ecosystems

3.1 E-flows assessments generally aim to identify the particular flow characteristics which are important for the health of rivers and dependent ecosystems. They also include environmental allocations, which are specific volumes captured in storages for release to be environmentally beneficial or water access entitlements committed to use for environmental purposes. There are various ecological functions performed by different river flow levels and both direct and indirect connections between the components of a flow regime and a variety of biota.

3.2 Depending on the use of the river, maintaining low flow as E-flows may not be good enough taking into account the requirement of its habitats. It is suggested that the water level for the E-flows should be kept at about two-third bankfull in the main river channel (the central part of the river). This can be interpreted based on the forces acting on the walls of the river. In natural river (usually of compound channel in shape), the momentum transfer between the main channel and the floodplains starts to occurs at about two-third bankfull flow.

3.3 The E-flows requirements can be for the following purposes: for water resources enhancement during low flow/low water level; for river bank stability; for maintaining the river biodiversity and ecosystem; maintaining the natural river morphology and others. Construction of boulders across the river channel at several places which behave as weirs, or other methods and techniques are necessary so as to maintain the river E-flows water level.

4. Methods of Determining Environmental Flows

4.1 There are many methods available, which are usually tailored to meet the specific requirements of each assessment. Many of the methodologies are country specific and no single country has yet developed an all-encompassing method. A range of methods has been developed in various countries that can be employed to define E-flows requirements. In broad terms, IUCN (2003) classified the methods into five categories: (1) Look-up tables; (2) Desk top analysis; (3) Functional analysis; (4) Habitat modeling; and (5) Holistic approach.

5. Examples for Environmental Flows Practices in Asia and the Pacific Region Studies on Environmental Flows in Malaysia

5.1 As E-flows are often site-specific, the minimum flow requirements are normally determined from its average natural flows for management purposes. Study on IRBM Langat River (2005), proposed a nominal amount equivalent to 20% of the estimated mean daily flow to be maintained in the river as E-flows base on Tennant Method (Hydrological Index Method).

The method states that 40% of the Average Annual Flow (AAF) of a river is an 'outstanding' minimum flow and 20% of the AAF is a 'satisfactory' minimum flow. The analysis carried out of flow data at Kajang gauging station stated that Average Daily Flow at the station is 7.5 m^3/s. As such, the outstanding and satisfactory minimum flow for Langat River at Kajang is 3.0 m^3/s (40%) and 1.5 m^3/s (20%) respectively.

5.2 For the Muda River Basin Study, the E-flows were regarded as river maintaining flow estimated based on percentages of low flows as suggested in Comprehensive Management Plan of Muda River Basin (JICA, 1995) and reported in DID (2009).

Studies on Environmental Flows in Australia

5.3 As part of broader water resource management reforms within the Murray-Darling Basin, the Water Act 2007 established the Commonwealth Environmental Water Holder (CEWH). These reforms are about ensuring sustainable use of a valuable water resource within the long-term sustainable limit so that ecosystems have sufficient water to perform key ecological functions into the future covering both surface and groundwater extractions. An Environmental Watering Plan was established to enable the environmental water of all holders and managers to be coordinated in a complementary basin-wide manner; and integration of E-flows requirements with salinity, water quality and natural resource management arrangements.

5.4 In determining and managing E-flows for the Shoalhaven River once the critical flow components of the natural river flow regime have been identified, various E-flows arrangements were assessed against the natural flow regime to determine which of the arrangements offer the greatest benefit for the river.

5.5 Using the desktop method, the estimated Environmental Water Requirements (EWR) flows and associated trigger levels for each month for Ansons River was determined.

Studies on Environmental Flows in China

5.6 In China the River Health and E-flows Project was undertaken to strengthen China's national approaches for improving river conditions through monitoring river health, assessing environmental flow requirements, developing policy responses and a national framework for E-flows.

5.7 The current E-flows practice in the Yellow River is similar to the low-risk environmental flow regime. The project has been designed to provide scientific support for the benefits of E-flows, so management decisions can be made with greater confidence (Speed et al., 2012)

Mekong River Basin

5.8 The Mekong River, a trans-boundary river is a vital resource that shapes the social, economic, cultural and ecological functions of the six countries through which it flows; China, Myanmar, People's Democratic Republic of Lao (Lao PDR), Thailand, Cambodia, and Vietnam.

5.9 The World Bank was the implementing agency for the Global Environment Facility (GEF) Water Utilization Project (WUP), which provided assistance to the Mekong River Commission (MRC) to implement some provisions of the agreement (World Bank, 2000). An environmental flows approach was developed and applied as the technical basis for determining acceptable minimum flows in support of the procedures enabling Article 6 of the Mekong Agreement.

1. Introduction

Emerging freshwater scarcity has been recognized as a global issue of the utmost important. There is growing awareness that increased water use by humans does not only reduce the amount of water available for industrial and agriculture development but has a profound effect on aquatic ecosystems and their dependent species. (Smakhtin, et al., 2004)

Studies did shows that the problem of sustainable water supply in the world has not been resolved. More than 40% of the world's population live in the condition of water stress and this percentage is estimated to grow to almost 50% by 2025. At the same time, human activities have severely affected the condition of freshwater worldwide. This capacity to support biodiversity appears to be highly degraded with many freshwater species facing rapid population decline or extinction. (Revenga, et al., 2000)

The driving forces for establishing water demand in water resources management may be based on resource scarcity, distribution system limitations, and/or efforts to manage operating costs. Responses to such needs can range from a conservation strategy that preserves available supplies to a resource-management strategy.

One of the efforts on resource-management strategy is in managing Environmental Flows (E- flows) in aquatic ecosystem. In aquatic ecosystems, such as rivers, wetlands, estuaries and near-coast marine ecosystems provide a great variety of benefits to people. These include 'goods' such as clean drinking water, fish and fibre, and 'services' such as water purification, flood mitigation and recreational opportunities (IUCN, 2003).

Rivers and other aquatic ecosystems need water and other inputs like sediment to stay healthy and provide benefits to people. E-flows are a critical contributor to the health of these ecosystems. The absence of E-flows puts at risk the very existence of ecosystems, people and economies. (IUCN, 2003)

E-flows can be defined as 'the water regime provided within a river, wetland or coastal zone to maintain ecosystems and their benefits where they are competing water uses and flows are regulated'. A distinction may be made between the amount of water needed to maintain an ecosystem in close-to-pristine condition, and that which might eventually be allocated to it, following a process of environment, social and economic assessment. (IUCN, 2003)

Water resources need to be managed to provide E-flows. Flow can be regulated by infrastructure, such as dams, or by diverting water from the system, for example pumping water away. There are thus different ways in which E-flows can be provided, such as modification of infrastructure or changes in water allocation policies and entitlements (IUCN, 2003). Regulating and maintaining certain water level in aquatic ecosystem can also improve healthy ecosystem.

Therefore, implementing E-flows requires either an active management of infrastructure such as dams, or a restrictive management, for example through reducing the abstractions for irrigation. When active flow management is applied, an entire flow regime can be generated, including low flows and floods. (IUCN, 2003)

2. Environmental Flows Concept

The goal of E-flows is to provide a flow regime that is adequate in terms of quantity, quality and timing for sustaining the health of the rivers and other aquatic ecosystems. The appropriate E-flows for a particular river will depend on the values for which the river system is to be managed. Those values will determine the decisions about how to balance environmental, economic and social aspirations and the uses of the river's waters (IUCN, 2003).

E-flows concept means enough water is left in our rivers, which is managed to ensure downstream environmental, social and economic benefits (The World Bank, 2003). The process to establish it may poses great challenges since it requires integration of input from expert teams of various disciplines and negotiations between stakeholders.

In this manner, the World Bank in Technical Note C.1, Environmental Flows: Concepts and Methods (2003) defines E-flows as: 'the water that is left in a river ecosystem, or release into it, for the specific purpose of managing the condition of that ecosystem'.

E-flows must be seen within the context of applying IWRM in catchments and river basins. E-flows will only ensure a healthy river if they are part of a broader package of measures, such as soil protection, pollution prevention, and protection and restoration of habitats. (IUCN, 2003)

2.1 The Science of Flow-Ecology Relationship

The relationship between IWRM, Ecohydrology and others with E-flows is illustrated in Figure 1.

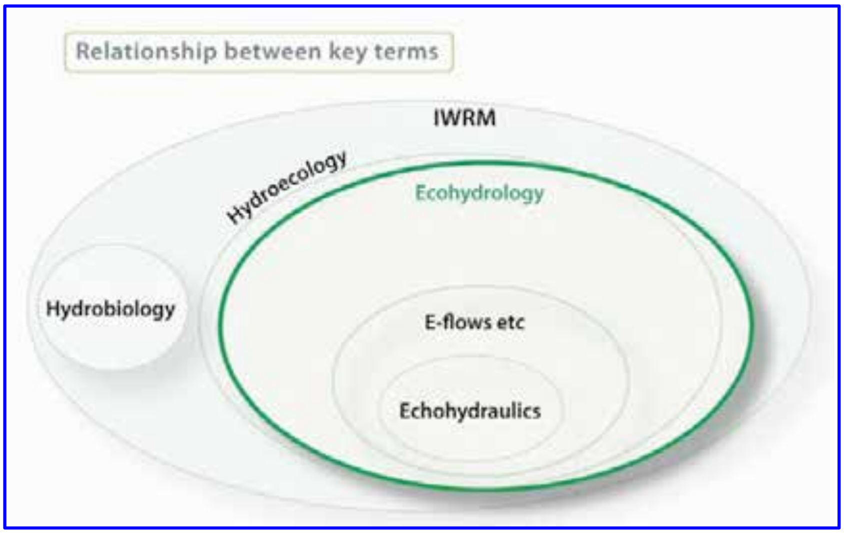


Figure 1: Relationship between IWRM, Hydroecology, Ecohydrology, Ecohydraulics and Environmental Flow (after Naiman, et al., 2007)

IWRM is a necessary framework for water resources management in considering all interactions of human with the water cycle. It promotes the coordinated development and management of water, land and related resources while enhancing the sustainability of natural ecosystem environment. Hydroecology, Ecohydrology, Ecohydraulics and Environmental Flows are branches of science that aim to support water management through improved representation relationships between hydrology, habitat, biodiversity, and ecosystem function (Naiman, et al., 2007).

Ecohydrology is an interdisciplinary field focusing on the interactions between water and ecosystems, including aquatic and terrestrial. These interactions may take place within water bodies, such as rivers and lakes, or on land, in forests, deserts, and other terrestrial ecosystems. The ecohydrology for sustainability is focused on an integrated understanding of biological and hydrological processes in order to create a scientific basis for a socially acceptable, cost-effective and systemic approach to the sustainable management of freshwater resources (UNESCO IHP, 2011). It encompasses all aspects of research related to flow-ecology.

E-flows can be considered as one of the sub-disciplines under Ecohydrology. Historically, E- flows referred to the minimum flows of water necessary to maintain aquatic biota and ecosystem process (Tharme, 2003; NSW EPA, 2006). In Asian countries, E-flows related primarily to the flows required to flush river systems and restore water quality (Kumara & Shivanna, 2015).

In broader sense, E-flows is necessary to maintain the biophysical components, ecological process and health of aquatic ecosystem and associated ecological goods and services (Artington et al., 2006).

2.2 Environmental Water Scarcity Indices

By comparing estimates of total water availability with estimates of environmental water requirements and actual total water use, it is possible to identify regions where human water use and the maintenance of functional ecosystems are in conflicts. Cases where total actual water use exceeds the difference between total water available and environmental water requirements may be referred to as cases of environmental water scarcity (Smakhtin, et al., 2014)

The concept of environmental water scarcity is illustrated graphically in Figure 2. These Diagrams illustrating (a) environmentally safe; (b) environmentally water scarce; (c) environmentally water stressed basin.

The entire box in these pictures represents the average total volume of water available in a basin such as MAR. MAR is the average of total annual volumes of water, which are recorded or calculated at a particular point in a river over a long period.

The bottom portion of the box represents the ecological water needs; that is the amount of water needed to sustain a functioning ecosystem and should be reserved for the environment. The rest of the box represents the amount of water that can potentially be put to other uses (agriculture, industry etc.) – utilizable water.

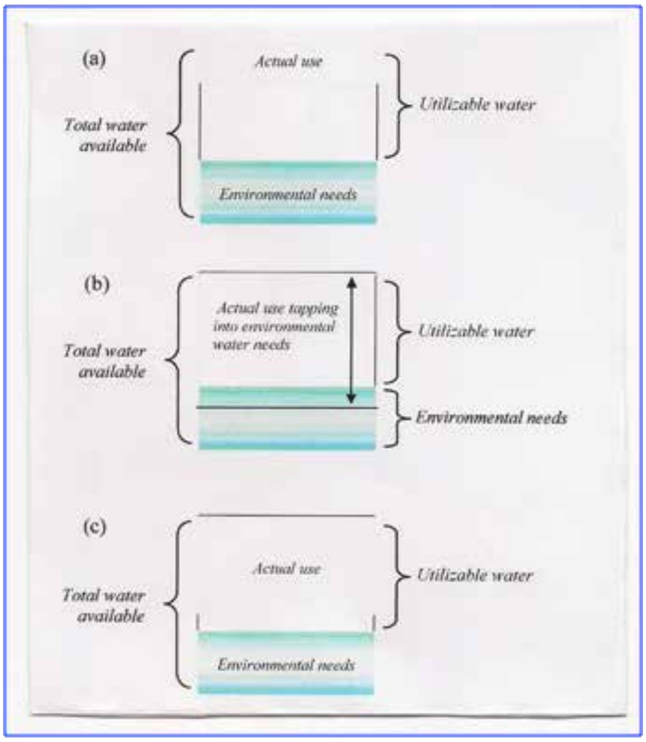


Figure 2: Diagrams illustrating (a) environmentally safe, (b) environmentally water scarce and (c) environmentally water stressed basins (after Smakhtin, et al., 2002, in Lim, C.H. & Roseli, 2009)

2.3 A Global Mapping of Environmental Water Requirements and Water Scarcity

The estimates of the long-term total annual water resources (MAR) calculated by WaterGAP2 model are presented in Figure 3. In general, the map reproduces the known pattern of water availability distribution over the globe.

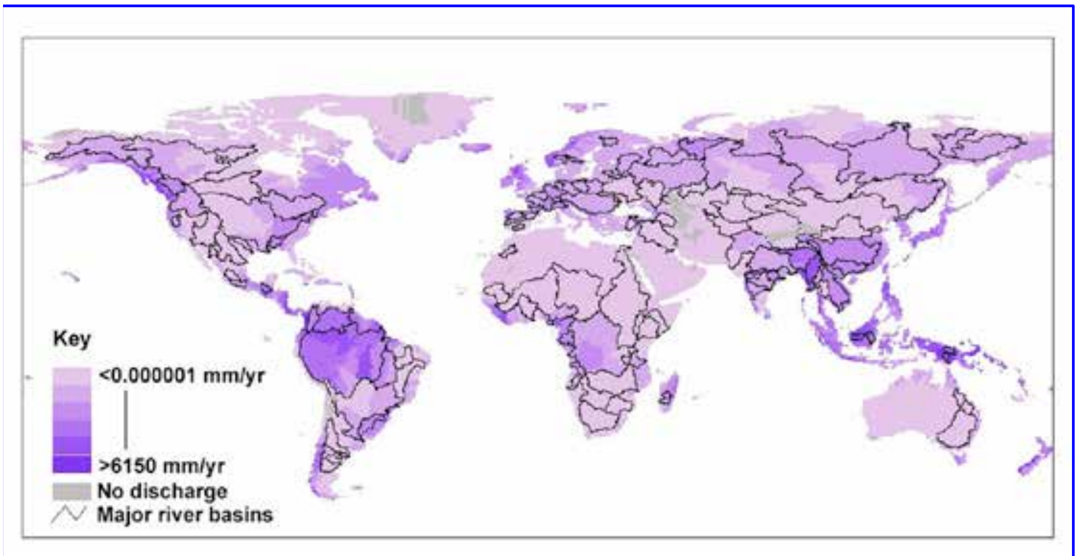


Figure 3: A map of long-term average annual water resources (MAR) by basin, calculated by the WaterGAP2 model (after Smakhtin, et al., 2002, in Lim, C.H. & Roseli, 2009)

Estimated environmental water requirements ranged globally from 20 to 50% of the MAR (Figure 4). In general, they may realistically range approximately from 10% to 70% of the natural MAR, depending on the sensitivity and importance of an aquatic ecosystem, the state in which it is intended to maintain the system, flow regime, and other characteristics.

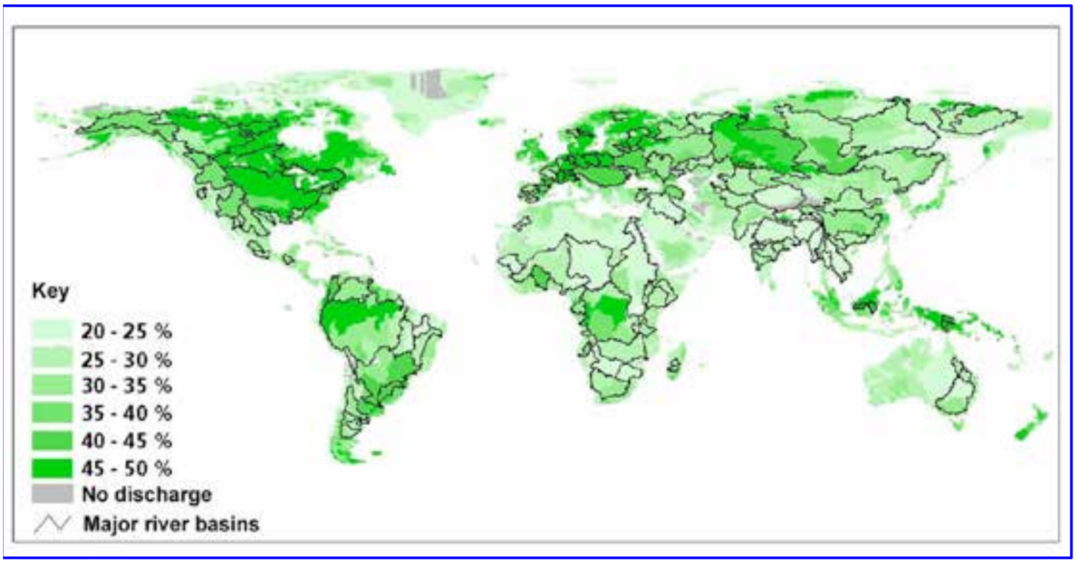


Figure 4: A map of estimated environmental water requirements as a percentage of total long-term average water resources (after Smakhtin, et al., 2002, in Lim, C.H. & Roseli, 2009)

The distribution of Water Stress Indicator (WSI) values over the globe (water withdrawal as a proportion of water available for human use) is presented on the map in Figure 5. It highlights basins where there is insufficient water to meet environmental water requirements and therefore it may be interpreted a first global picture of environmental water scarcity by basin.

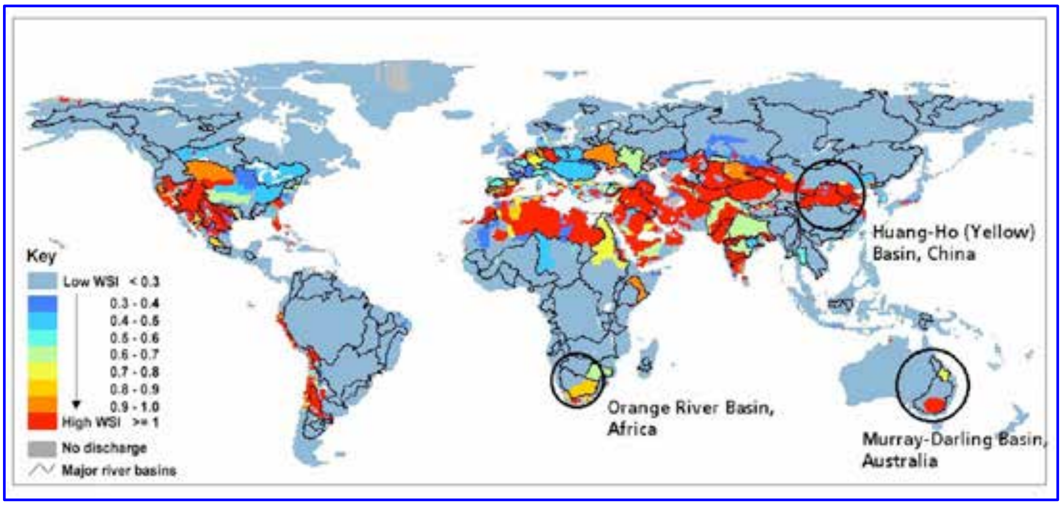


Figure 5: A map of a water stress indicator which takes into account environmental water requirements in river basins (after Smakhtin, et al., 2002, in Lim, C.H. & Roseli, 2009)

WSI = Withdrawals/(MAR-EWR)

Where, WSI – water stress indicator
MAR – average total volumes of water
EWR – environmental water requirement

Figure 6 reflects the traditional way in which water scarcity is assessed. It compares water withdrawals to the water availability without taking into account the environmental water requirements. The comparison of maps in Figures 5 and 6 illustrates that when the ecosystem's water requirements are taken into account, more basins show a higher degree of water stress.

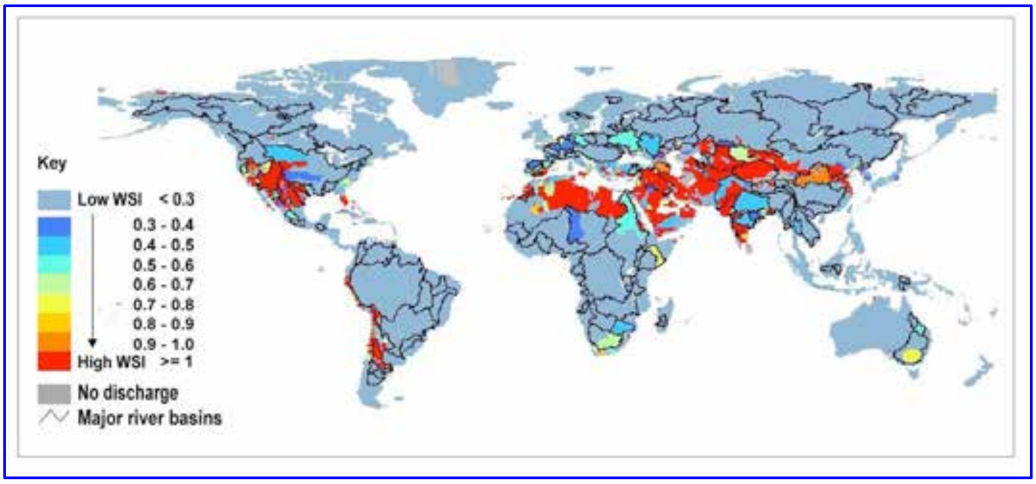


Figure 6: A map of the "traditional" water stress indicator (water withdrawals as a proportion of the long-term average total water resources) (after Smakhtin, et al., 2002, in Lim, C.H. & Roseli, 2009)

3. Environmental Flows Monitoring and Management Programme (river, lake, dam)

E-flows Programme will need to strike a balance between water allocations to satisfy the ecological water requirement and other water use needs like those of hydropower generation, irrigation, drinking water or recreation. Developing an E-flows programme therefore means articulating the core values on which to base decisions, determining what outcomes are sought and defining what trade-offs those will entail. A number of considerations need to be taken into account when starting with E-flows. (IUCN, 2003)

First of all, river and drainage systems need to be considered in their context. In a physical sense, this means considering the system from its headwaters to the estuarine and coastal environments and including its wetlands, floodplains and associated groundwater systems. In terms of values, this means considering environmental, economic, social and cultural values in relation to the entire system. A wide range of outcomes, from protection to serving the needs of industries and people are to be considered for possible inclusion in an E-flows programme. (IUCN, 2003)

In a river system where water has been over-allocated to consumptive use, E-flows might be provided simply to have ecosystems that function sufficiently to provide a sustainable base for present and future consumptive and in-stream uses. (IUCN, 2003)

4. Environmental Flow Management Assessment and Strategies

E-flows assessments generally aim to identify the particular flow characteristics which are important for the health of rivers and dependent ecosystems. These characteristics denote the E-flows requirements of that river system, which are often expressed as E-flows objectives or targets in water plans. (Australian Government, Land and Water Australia, 2007)

Water plans typically include various strategies to achieve these flow objectives. These include E-flows rules relating to extraction or system operation such as (Australian Government, Land and Water Australia, 2007):

- Limiting extraction volumes
- Constraining timing and rate of extraction to protect designated flow events or characteristics (example cease to pump levels, "protected" flow events)
- Requiring certain flow characteristics to be achieved regardless of water supply requirements (example minimum flows, "transparent" or "translucent" dam release rules)

They also include environmental allocations, which are specific volumes captured in storages for release when it is considered by an environmental water manager to be environmentally beneficial or water access entitlements committed to use for environmental purposes. In some cases environmental rules and allocations are tied together, example requirements for translucent dam releases may be tied to an allocation held in storage rather than simply being an operational requirement (Australian Government, Land and Water Australia, 2007).

How E-flows can be applied and plan for mobilising action in river basin management: The six (6) learning objectives (IUCN, 2008) are as follows:

1. Understanding the principles of E-flows;
2. Familiarization with methods for flow assessment and options for managing infrastructure;
3. Understanding of how to define flow scenarios and negotiate flow regimes with stakeholders;
4. Development of an implementation framework for E-flows, encompassing governance and economic requirements;
5. Creation of roadmaps for fostering cooperation and social learning, generating political momentum and managing change;
6. Formulation of action plans for application of E-flows in management plans for project basins.

The Checklist on Application of E-flows in River Basin Management from GEF IW: Learn Regional Workshop Foz do Iguacu, Brasil 11 – 15 February, 2008 finding as reported in IUCN (2008) is shown in Appendix A.

5. Ensuring Clean, Living, Pristine River System

E-flow is the amount of water needed in a water course to maintain healthy ecosystem. One of the ways for enhancing the management of water resources towards sustainable environment is by ensuring clean, living and vibrant river system. These conservations of ecosystem require approaches such as stream channel morphology (dimension, pattern and profile), in-stream structure, floodplain connection, riverbank stabilization, riparian corridor vegetation and habitat enhancement. For examples: restoring meanders; creating stone riffles for self-purification mechanisms; floodplain that provide temporary storage for floodwaters, storage for sediment from watershed to settle before flowing into the river, space for channel to migrate over time; bank vegetation in riparian zone and riverbanks and slope for watercourse quality, varying river morphology for habitat enhancement; riverbank stabilisation using combination of hard and natural river structures and others. The ecological functions performed by different river flow levels are shown in Table 1. Both direct and indirect connections between the components of a flow regime and a variety of biota, examples of these connections can be seen from Table 1.

Table 1: Ecological functions performed by different river flow levels (adapted from Postel and Richter, 2003)

Flow Component	Ecological Roles
Flow Component Ecological Roles	Normal level • Provide adequate habitat space for aquatic organisms • Maintain suitable water temperatures, dissolved oxygen, and water chemistry • Maintain water table levels in floodplain, soil moisture for plants • Provide drinking water for terrestrial animals • Keep fish and amphibian eggs suspended • Enable fish to move to feeding and spawning areas • Support hyporheic organisms (living in saturated sediments) Drought level • Enable recruitment of certain floodplain plants • Purge invasive, introduced species from aquatic and riparian communities • Concentrate prey into limited areas to benefit predators
High pulse flows	• Shape physical character of river channel including pools, riffles • Determine size of stream bed substrates (sand, gravel, cobble) • Prevent riparian vegetation from encroaching into channel • Restore normal water quality conditions after prolonged low flows, flushing away waste products and pollutants • Aerate eggs in spawning gravels, prevent siltation • Maintain suitable salinity conditions in estuaries
Floods	• Provide migration and spawning cues for fish • Trigger new phase in life cycle (e.g., insects) • Enable fish to spawn on floodplain, provide nursery area for juvenile fish • Provide new feeding opportunities for fish, waterfowl • Recharge floodplain water table • Maintain diversity in floodplain forest types through prolonged inundation (i.e. different plant species have different tolerances) • Control distribution and abundance of plants on floodplain • Deposit nutrients on floodplain • Maintain balance of species in aquatic and riparian communities • Create sites for recruitment of colonizing plants • Shape physical habitats of floodplain • Deposit gravel and cobbles in spawning areas • Flush organic materials (food) and woody debris (habitat structures) into channel • Purge invasive, introduced species from aquatic and riparian communities • Disburse seeds and fruits of riparian plants • Drive lateral movement of river channel, forming new habitats (secondary channels, oxbow lakes) • Provide plant seedlings with prolonged access to soil moisture

An example of a natural river system cross-section with bankfull flow and water level maintaining the low flow is shown in Figure 7. The lowest form of the low flow is the baseflow, which is to be differentiated from E-flows although it may be taken as component of the latter. Baseflow is the portion of stream flow that is not from runoff but comes from groundwater which seeps into a channel slowly over time. It is the primary source of running water in a stream during dry weather (DID, 2009). Depending on the use of the river, maintaining low flow as E-flows may not be good enough taking into account the requirement of its habitats.

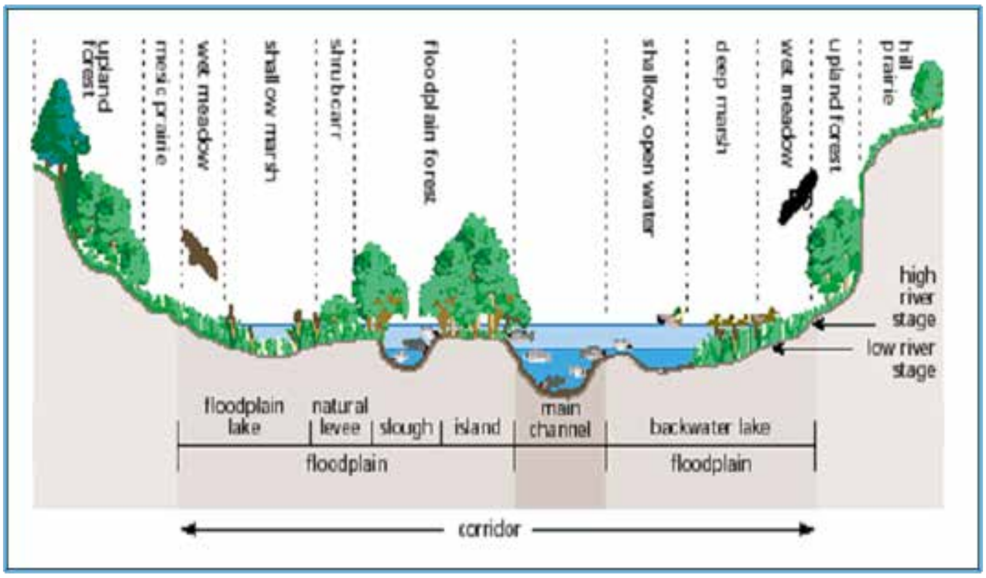


Figure 7: A natural river showing water at high river stage and low river stage (after DID, 2009)

Figure 8 shows an example of a river in its natural state with its main channel and floodplains. The associated forces and the momentum transfers from the main channel are shown in Figure 9. By understanding this river hydraulics phenomena and the relationship of the wave speed against discharge for natural rivers (Figures 10 and 11), the corresponding shape for the design of a representative natural river section from study by Roseli (1999) is shown in Figure 12.

There are storage areas that need to be considered as a result of the momentum transfer. It is suggested that the water level for the E-flows should be kept at about two-third bankfull in the main river channel (the central part of the river). This can be interpreted by Figure 9 based on the forces acting on the walls of the river. In natural river (usually of compound channel in shape), the momentum transfer between the main channel and the floodplains starts to occur at about two-third bankfull flow.

Figure 8: River at its natural environment (image may be subject to copyright)

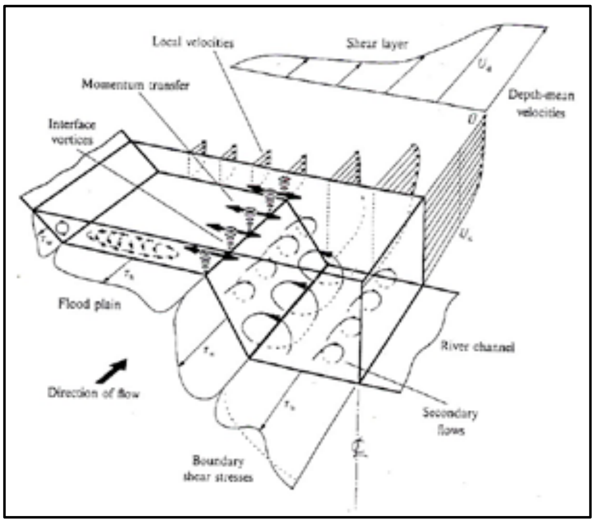


Figure 9: Hydraulic Parameters Associated with Overbank Flow (after Knight and Shiono, 1996)

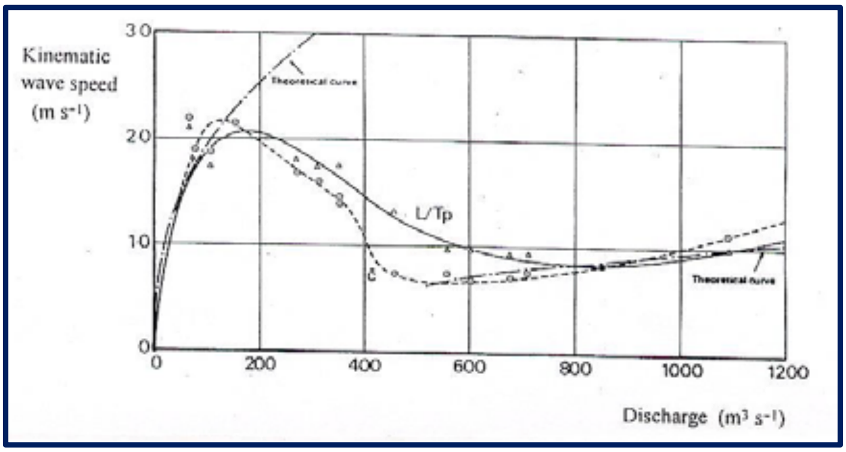


Figure 10: Example of wave speed discharge – curve for River Wye, Erwood to Belmont Reach, United Kingdom (after NERC, 1975)

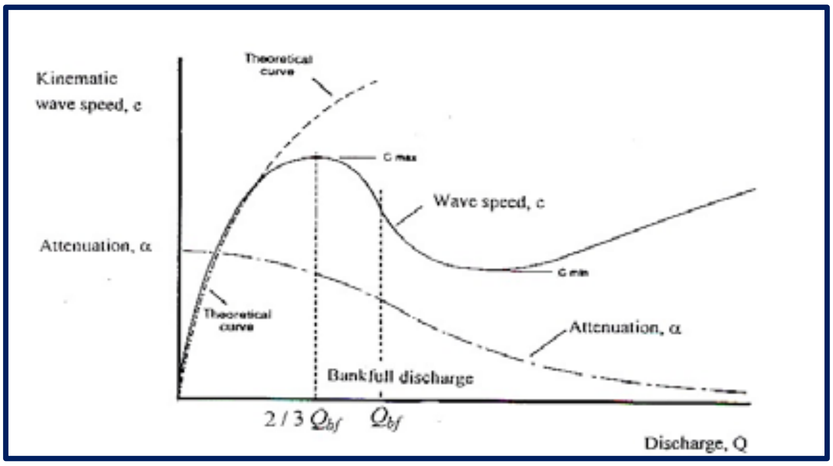


Figure 11: Typical kinematic wave speed – discharge and attenuation parameter – discharge curve (after Price, 1973; HR Wallingford, 1994)

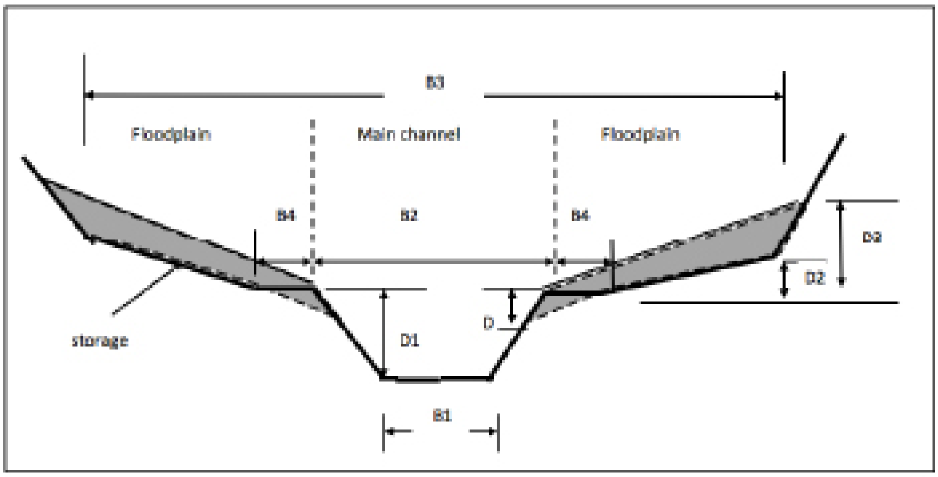


Figure 12: A typical compound channel with the concept of natural waterway features (after Roseli, 1999)

The E-flows can be for the following purposes:

a. For water resources enhancement during low flow/low water level;
b. For river bank stability;
c. For maintaining the river biodiversity and ecosystem;
d. To maintain the natural river morphology and others.

Construction of boulders across the river channel at several places which behave as weirs, or other methods and techniques are deem necessary so as to maintain the river E-flows water level.

5.1 Restoring Environmental Flow Regimes through River Restoration Projects

Many river restoration projects are focusing on restoring E-flows regimes to improve ecosystem health in rivers that have been developed for water supply, hydropower generation, flood control, pollution control, navigation, and other purposes. In efforts to prevent future ecological damage, water supply planners in some parts of the world are beginning to address the water needs of river ecosystems proactively by reserving some portion of river flows for ecosystem support (Richter, 2006).

5.2 Ecosystem Flow Downstream of Dams

Natural river systems around the world were heavily modified to serve a variety of human purposes, including supplying water to cities and farms, generating electric power, facilitating navigation, and controlling floods and pollutions. (Richter, 2006)

Dams have facilitated human utilization and control of rivers by enabling water managers to convert natural flow variability into water releases governed by human needs. By capturing high river flows and releasing the water in a carefully controlled manner, dam managers can deliver steady and dependable water supplies to downstream areas, protect settlements from floods, or generate power. As a consequence of this water control, river flows below dams commonly bear little resemblance to their natural variability. (Richter, 2006)

E-flows restoration or protection is ideally suited to an adaptive management approach. Water managers can often exert a high degree of control of water flows through their operations of dams or water diversions, and many of their management actions can be treated as experiments that can be monitored to evaluate their influence on river ecosystem health (Ward and Stanford, 1993; Poff et al., 2003).

Examples on the recommendation of ecosystem flows below a dam is shown in Appendix B.

6. Methods of Determining Environmental Flows

There is no single standardised method for estimating E-flows. Rather, there are many methods available, which are usually tailored to meet the specific requirements of each assessment. Mentioned in DID (2009), currently, there are over 200 approaches for determining E-flows, which are being proposed or implemented in more than 50 countries worldwide (Santa Fe Watershed Association, 2007). Many of the methodologies are country specific and no single country has yet developed an all-encompassing method.

As reported by the Department of Primary Industries, Parks, Water and Environment (DPIPWE), Hobart, Tasmania, Australia (2009), at the beginning, most appropriate methods available at that time were used focusing largely on minimum flow requirements for in- stream fauna (such as fish and invertebrates). However, new methodologies that incorporate natural variability in stream flow, and the high flow water requirements of entire riverine ecosystems, are now being used by DPIPWE to develop E-flows for catchments. For example, the methodology developed by DPIPWE (Tasmanian Environmental Flow Framework (TEFF)) outlines the methods that are used in catchments with high water demand. Broadly, the TEFF aims to link the biological components and physical heterogeneity present within a river to specific flow events, and to link these flow events to specific E-flows objectives. The process involves four main steps:

1. Identify freshwater ecosystem values in each catchment in order to define the objectives of the E-flows assessment. Develop conceptual models that identify the ecosystem processes that support these values.
2. Identify representative river reaches, conduct assessments using hydraulic and hydrological models to characterise physical habitat and biological diversity of the system, and identify specific flow events that relate to these attributes.
3. Conduct hydrological analyses of flow data to define the pattern of occurrence of important flow events and the availability of important habitats for fauna.
4. Recommend a flow regime that meets the objectives of the E-flows assessment, including rules for water abstraction.

A range of methods has been developed in various countries that can be employed to define E-flows requirements. In broad terms, IUCN (2003) classified the methods into five categories:

1. Look-up tables
2. Desktop analysis
3. Functional analysis
4. Habitat modeling
5. Holistic approach

6.1 Look-up Tables

The most commonly applied methods worldwide to define targeted river flows are rules of thumb based on simple indices given in look-up tables. The most widely employed indices are purely hydrological, but some methods employing ecological data were developed in the 1970s.

As mentioned in IUCN (2003), for example in regulating abstractions in the UK, an index of natural low flow has been employed to define the E-flows. Often used is the Q95 Index: the flow that is equalled or exceeded for 95% of the time. In other cases, indices of less frequent drought events have been used such as the mean annual minimum flow. The Q95 Index was chosen purely on hydrological grounds. However, the implementation of this method often requires the use of ecological information.

The Tennant (1976) method is another index method used. It was developed using calibration data from hundreds of rivers in the mid-Western states of the USA to specify minimum flows to protect a healthy river environment. Percentages of the mean annual flow are specified that provide different quality habitat for fish e.g. 10% for poor quality (survival), 30% for moderate habitat (satisfactory) and 60% for excellent habitat. This method can be used elsewhere, but the exact indices would need to be re-calculated for each region. In the mid- Western USA, the indices have been widely used in planning at the river basin level. However, these are not recommended for specific studies and where negotiation is required.

6.2 Desktop Analysis

The methods focus on analysis of data. Desk-top analysis methods use existing data such as river flows from gauging stations and/or fish data from regular surveys. If needed some data may be collected at a particular site or sites on a river to supplement existing information. (see Darby and Sear, 2008)

Desktop analysis methods can be sub-divided into those based purely on hydrological data, those that use hydraulic information (such as channel form) and those that employ ecological data. Hydrological desk-top analysis methods examine the whole river flow regime rather than pre-derived statistics. (see Darby and Sear, 2008)

An example of a hydrological desk-top analysis method is the Richter method. The method defines benchmark flows for rivers where the primary objective is the protection of the natural ecosystem. The method identifies the components of a natural flow regime, indexed by magnitude (of both high and low flows), timing (indexed by monthly statistics), frequency (number of events) and duration (indexed by moving average minima and maxima). (see Darby and Sear, 2008)

6.3 Functional Analysis

The functional analysis methods include those that build an understanding of the functional links between all aspects of the hydrology and ecology of the river system. These methods take a broad view and cover many aspects of the river ecosystem, using hydrological analysis, hydraulic rating information and biological data. (see Darby and Sear, 2008)

IUCN (2003) mentioned that in Australia, several functional analysis methods have been developed, including the Expert Panel Assessment Method, the Scientific Panel Approach and the Benchmarking Methodology. As with the Building Block Methodology (BBM) developed in South

Africa, all aspects of the hydrological regime and ecological system are studied making judgments about the ecological consequences of various quantities and timings of flow in the river, using a mix of available and newly acquired data.

6.4 Habitat Modeling

Difficulties exist in relating changes in the flow regime directly to the response of species and communities. Hence methods have been developed that use data on habitat for target species to determine ecological flow requirements. Within the environmental conditions required by a specific freshwater species, it is the physical aspects that are most heavily impacted by changes to the flow regime. The relationship between flow, habitat and species can be described by linking the physical properties of river stretches, such as depth and flow velocity, at different measured or modeled flows, with the physical conditions that key animal or plant species require. Once functional relationships between physical habitat and flow have been defined, they can be linked to scenarios of river flow. (IUCN, 2003)

As reported by IUCN (2003), the first step in formulating this method for rivers was published in 1976. This led to the more formal description of a computer model called PHABSIM (Physical Habitat Simulation) by the US Fish and Wildlife Service. Over the years, this has led to other models that follow basically the same method. As implemented in a number of software packages, the traditional PHABSIM method uses one-dimensional hydraulic models, adapted to handle low flow conditions and to model cross-sectional velocities. These are coupled with representations of habitat suitability or preference to define how habitat changes with flow. The extent of the change will be specific to the species under consideration, and is frequently different for different developmental stages of individual species.

The physical habitat modeling method has now been adapted for use in many countries. It has been used to estimate the effects, in terms of usable physical habitat, of historical or future anticipated changes in flow caused by abstraction or dam construction. The method has evolved from steady-state analysis of flows for given levels of habitat to time-series analysis for the entire flow regime in the river. In turn, the techniques of analysis have developed from looking at simple flow and habitat duration curves, to more in-depth analysis of habitat reductions under various scenarios. This considers a range of scenarios against a baseline, commonly of natural flows, and allows scenarios to be compared quantitatively. (IUCN, 2003)

6.5 Holistic Approach

IUCN (2003) also mentioned about holistic approach methods. Many early applications of E- flows setting were focused on single species or single issues. The E-flows were set to maintain critical levels of habitat for these species (such as fishes), including sediment discharge, flow velocity, and river depth.

More and more methods now take a holistic approach that explicitly includes assessment of the whole ecosystem, such as associated wetlands, groundwater and estuaries which also account for all species that are sensitive to flow, such as invertebrates, plants and animals, and address all aspects of the hydrological regime including such as floods, droughts, and water quality. The fundamental principle is to maintain natural variability of flows. Overall a more holistic approach is increasingly found in all E-flows methods. (IUCN, 2003).

Generally, holistic approaches make use of teams of experts and may involve participation from stakeholders so that the procedure is holistic in terms of interested parties in addressing various issues. Where methods have the characteristic of being holistic they clearly have the advantage of covering the whole hydrological-ecological-stakeholder system. As pointed out by IUCN (2003), the disadvantage is that it is expensive to collect the relevant data.

Tharme (2003) groups the E-flows methodologies into four categories: Hydrologic methods (such as Tennant method and Q90 method); Hydraulic rating (such as wetted perimeter method); Habitat simulation (such as IFIM and PHABSIM); and Holistic methods such as Building Blocks Methodology). Much of the explanation can be obtained from DID (2009) such as shown in Appendix C.

7. Examples for Environmental Flows Practices in Asia and the Pacific Region

7.1 Studies on Environmental Flows in Malaysia

Increasing water demand for irrigation, domestic and industrial consumption and hydropower, together with catchment developments as well as encroachment into the riparian land, have led to decline in the health of the water-dependent ecosystems (DID, 2005) as reported in DID (2009). It would therefore be desirable that minimum E-flows for each river basin be specified that will allow and facilitate measures to be taken to avoid the decline of the valuable ecosystem.

The form of such environmental flow can simply be a specified discharge value (hydrological methods), or the specification of a water depth to provide habitat for fishes (hydraulic methods), or as complex as a description of a completely modified flow regime to maintain a whole river and floodplain ecosystem (Habitat quality and Holistic methods) (DID, 2009). As E-flows are often site specific, the minimum flow requirements are normally determined from its average natural flows for management purposes (hydrological methods) (DID, 2005).

The National Water Resources Study (2000), for example, used a rule-of-thumb of 10% Average Annual Flow (AAF) as the minimum flow required for planning purposes. Such minimum flow releases have also been used for the previous and similar water resources study in Malaysia. Another example, a 2005 study on Integrated River Basin Management for Langat River (see Lim, C.H. & Roseli, 2009), proposed a nominal amount equivalent to 20% of the estimated mean daily flow to be maintained in the river as E-flows base on Tennant Method (Hydrological Index Method). The method states that 40% of the Average Annual Flow (AAF) of a river is an ‘outstanding’ minimum flow and 20% of the AAF is a ‘satisfactory’ minimum flow. The analysis carried out in the Study with 22 years of flow data at Kajang gauging station stated that Average Daily Flow at the station is 7.5 m^3/s. As such, the outstanding and satisfactory minimum flow for Langat River at Kajang is 3.0 m^3/s (40%) and 1.5 m^3/s (20%) respectively. The AAF of ungauged catchments in Peninsular Malaysia may be estimated from Water Resources Publication No.12 (1982). (See also Academy of Sciences Malaysia, 2010)

For the Muda River Basin Study, the E-flows were regarded as river maintaining flow estimated based on percentages of low flows for four key components as suggested in Comprehensive Management Plan of Muda River Basin (JICA, 1995) and reported in DID (2009) as listed below (Section 7.1.1 to 7.1.5).

The river maintenance flow is essential for maintaining the appropriate river environment, particularly, the river water quality during the period of low flow regime. The necessary river maintenance flow is determined in due consideration of the four (4) dominant factors:

1. Necessary discharge to maintain the appropriate river water quality;
2. Necessary discharge to conserve natural low flow regime;
3. Necessary discharge to conserve river ecology; and
4. Necessary discharge to maintain river scenery.

7.1.1 Discharge Necessary to Maintain an Acceptable Water Quality

The target is to upgrade or maintain at least the water quality standard of Class II for all rivers. Class II water will only necessitate conventional treatment if abstracted for water supplies while Class III waters would require extensive treatment.

The river flow discharge was estimated by the following formula assuming that the discharge needs to dilute the Biochemical Oxygen Demand (BOD) concentration to less than 6 mg/l, which is the allowable level for use of treated drinking water.

$$Qm = 1000 \times PL/BOD(R)$$

Where,

*Q*m	: Necessary river maintenance discharge (m^3/s)
PL	: Gross weight of pollution loads generated at pollutant sources (mg/s)
BOD(R)	: Required BOD concentration (assumed as 6 mg/l)

7.1.2 Discharge Necessary to Conserve Natural Low Flows

Natural low flows are defined as the naturally occurring low flows due to prolonged periods without rain and that the outflow of water is from baseflow and subsurface storage in the basins. The 1-day and 7-day low flows are reflective of natural low flow regimes and their return periods indicate water availability in the river system during low flow episodes. The 7-day low flow with a return interval of once in every 25 years is adopted as the minimum discharge assumed necessary to conserve the natural low flow regimes, river aquatic ecosystems and streambank stability. The 50-year return interval flow is not taken into consideration since the effects of such low flows on the aquatic life forms would have been quite drastic, and many aquatic and riparian species may not be able to survive such prolonged droughts and low flows.

7.1.3 Discharge Necessary to Conserve River Ecology

Certain stretches along rivers are active breeding locations for fish and other aquatic life, which are also sensitive to ecological alterations. The survival of these sensitive areas depends on the depth, volume and the quality of water in the river systems. Fish survival in natural rivers depends on certain limits of minimum water depth and velocity for breeding and swimming. There must also be sufficient water available for dilution so that the fish can survive in areas with high BOD loading in the water.

The most important consideration is the availability of water for reproduction, where a minimum depth of water is critical for their life cycle and space for comfort swimming. The JICA Report (1995) advocated a minimum depth of 30 cm to 50 cm for fishes in Muda River. In the absence of rating curves to derive the relationship between volumetric flow rates with depth, a minimum discharge for Class II waters could be adopted as the minimum requirements for fish and aquaculture.

7.1.4 Discharge Necessary to Maintain River Scenery

Picturesque and beautiful river scenery has always invoked tranquility and human well-being. The scenic quality of river depends, amongst other, on water quality, flow characteristics, riparian and stream bank vegetation. Places with waterfalls and cascades with rock boulders and sand banks could be converted to tourist attraction sites. With reference to the environmental guidelines in Japan, it was assumed that about 20% of the river channel has to be constantly covered with water to maintain desirable river scenery.

7.1.5 Discharge Necessary to Prevent Salt-Water Intrusion

Near coastal areas, consideration should be given to maintain the fresh water aquatic habitat and prevent salt-water intrusion at low flows.

7.1.6 Case Study from EIA Reports

The following are taken from Part of Section 6.4: Surface Hydrology from the Executive Summary, Volume 1 of the Report (2008), and the Detailed Environmental Impact Assessment for Hulu Terengganu Hydroelectric Project, Tenaga National Berhad which is a multimillion dollar dam project.

The minimum flow analysis was performed to determine the magnitude and frequency of low flow for the proposed project site. Analysis of minimum flow was determined based on three methods: (1) Mean Annual Minimum Flow (MAM), which is 4,520 m^3/s for Terengganu Mati River and 0.976 m^3/s for Tembat River. (2) 10% of the average annual flow; 4 m^3/s for Terengganu Mati River and 0.55 m^3/s for Tembat River. (3) Based on the SMEC Engineering study, minimum daily flow was 3.3 m^3/s (Terengganu Mati River) and 0.80 m^3/s for Tembat River. During reservoir filling and dam operation, the river stretches downstream of the dam (Tembat River 4.14 km and Terengganu Mati River 4.82 km) will be dried up if no water is released during reservoir filling. The river ecology will be completely destroyed. To mitigate the impact a minimum flow of 1.0 m^3/s for Terengganu Mati River and 0.5 m^3/s for Tembat River is recommended. (Academy of Sciences Malaysia, 2010)

We can see that on the minimum flow values to sustain the river ecology, biodiversity and ecosystem based on certain design discharge as mentioned in the report is not good enough. Sand bars could still be formed as already experienced for reservoir/dam project in Malaysia. This will hinder flow, obstruct the sediment transport, rivers become shallow and reduce the river carrying capacity. (Academy of Sciences Malaysia, 2010)

7.2 Studies on Environmental Flows in Australia

The diagram in Figure 13 shows a section of unregulated river above the dam. Extraction at A will affect flow characteristics downstream. Environmentally important characteristics can be maintained by constraining the volume, rate and timing of extraction. The flow rules in water sharing plans for unregulated rivers typically specify how this should be done. In the regulated section of a river the flow regime is totally changed by the operation of the dam. Restoration of important environmental flow characteristics normally requires releases of water to be made at times which are less than optimal for other users.

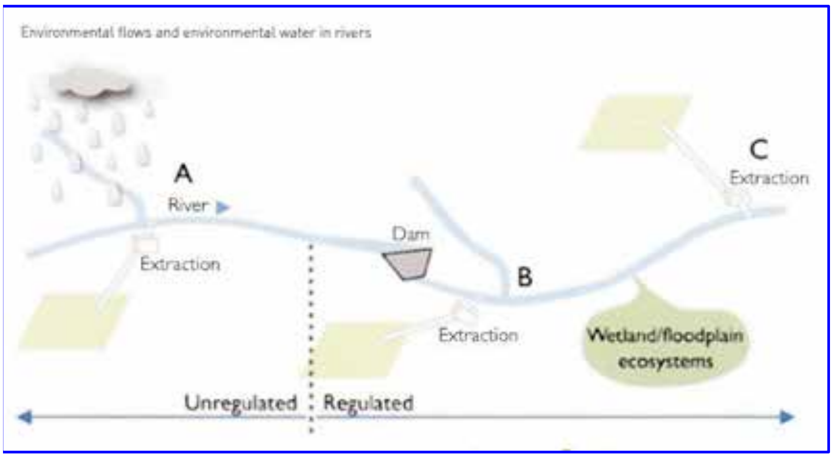


Figure 13: Unregulated and Regulated river sections (after LWA, 2007)

A framework suitable for use in regulated and unregulated river systems is outlined in Appendix D. The key features are shown in the framework has eight main steps, including four multidisciplinary workshops.

Methods addressing flow requirements for geomorphological purposes; methods addressing the flow requirements of wetland, riparian and floodplain vegetation; methods addressing the flow requirements of fish; the influence of river flows on coastal fisheries and methods addressing the flow requirements of aquatic invertebrates can be obtained from Arthington and Zalucki (1998).

7.2.1 The Case of Murray-Darling Basin

The Murray-Darling Basin (Figure 14) drains an area of 1.073 million km^2, with the Murray and Darling rivers alone comprising approximately 5300 km.

Figure 14: The Murray-Darling Basin (after Humphriesa et al., 1999)

As part of broader water resource management reforms within the Murray-Darling Basin, the Water Act 2007 established the Commonwealth Environmental Water Holder (CEWH). These reforms are about ensuring sustainable used of a valuable water resource within the long-term sustainable limit so that ecosystems have sufficient water to perform key ecological functions into the future. These cover both surface and groundwater extractions for consumptive use, which allows flows to return to rivers and wetlands to restore the health of the system, a significant increase in the quantity of water to provide ecologically beneficial wetting/drying and variable flow regimes. An Environmental Watering Plan was established to enable the environmental water of all holders and managers to be coordinated in a complementary basin-wide manner; and integration of E-flows requirements with salinity, water quality and natural resource management arrangements. (DEWHA, 2009)

Table 2 provides guidance as to how water should be used under different climatic and flow conditions. These conditions will impact upon how much water is available in the system. Subject to system constraints, in some cases water would be used in conjunction with natural flows and in some cases with water made available by delivery partners. The system as a whole would be more reflective of the prevailing climatic conditions, which would not only be impacting on the volume of held environmental water, but on the total volume of water flowing through the system. (DEWHA, 2009)

Table 2: Proposed ecological watering objectives under different water resource availability scenarios (after DEWHA, 2009)

	Extreme Dry	Dry	Median	Wet
Ecological watering objectives	Avoid damage to key environmental assets	Ensure ecological capacity for recovery	Maintain ecological health and resilience	Improve and extend healthy and resilient aquatic ecosystem
Management objectives	• Avoid critical loss of threatened species and communities • Maintain key refuges • Avoid irretrievable damage or catastrophic events	• Support the survival and growth of threatened species and communities including limited small-scale recruitment • Maintain diverse habitats • Maintain low flow river and floodplain functional processes in sites and reaches of priority assets	• Enable growth, reproduction and small-scale recruitment for a diverse range of flora and fauna • Promote low- lying floodplain- river connectivity • Support medium flow river and floodplain functional processes	• Enable growth, reproduction and large-scale recruitment for a diverse range of flora and fauna • Promote higher floodplain-river connectivity • Support high flow river and floodplain functional processes
Management actions	• Water refugia and sites supporting threatened species and communities • Undertake emergency watering at specific sites of priority assets • Use carryover volumes to maintain critical needs	• Water refugia and sites supporting threatened species and communities • Provide low flow and freshes in sites and reaches of priority assets • Use carryover volumes to maintain follow-up watering	• Prolong flood / highflow duration at key sites and reaches of priority assets • Contribute to the full-range of in-channel flows • Use carryover to provide optimal seasonal flow patterns in subsequent years	• Increase flood / highflow duration and extent across priority assets • Contribute to the full range of flows incl. overbank • Use carryover to provide optimal seasonal flow patterns in subsequent years

The diagram shown in Figure 15 illustrates how a decision framework may arrive at an appropriate matching of available water with priority watering actions. It incorporates the elements of the nine criteria used for prioritising watering actions would be governed by the overall objectives, and the practical application.

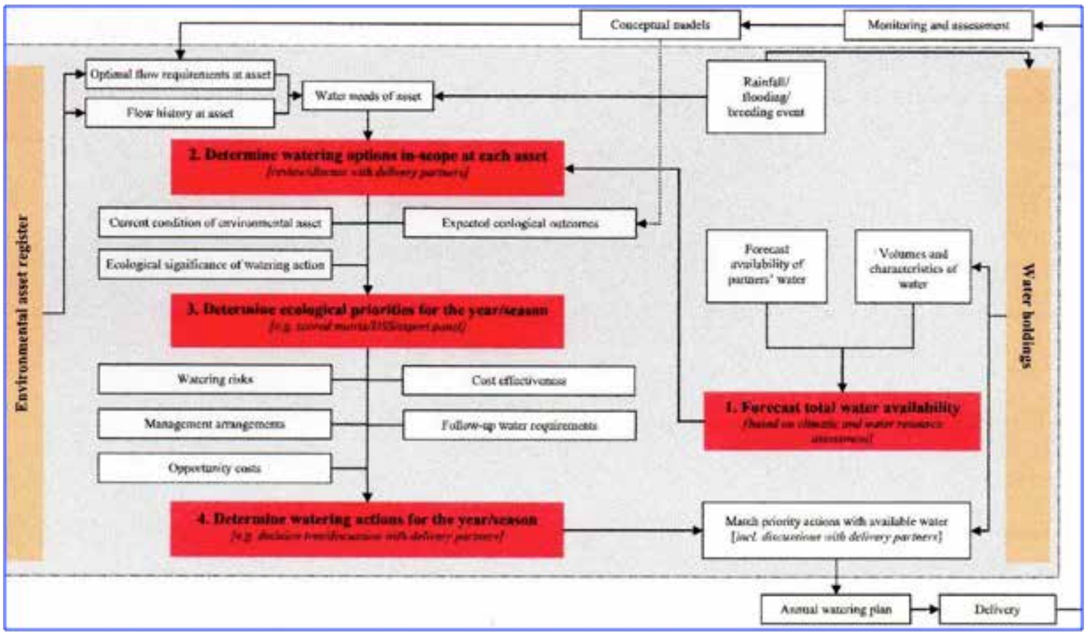


Figure 15: Prioritization framework for matching environmental water with environmental assets (after DEWHA, 2009)

One of the studies related to E-flows water level both in the main channel and floodplains was conducted to link between freshwater fishes and their environment. From observations, that increases in water level in aquaculture ponds initiate spawning in some species, and from A perception has emerged of the importance of flooding and the floodplain in the life cycles of Murray-Darling fishes in general. However, there is little confirmatory evidence of the use of temporary floodplain habitats by larvae, juveniles or adults. Murray-Darling fish species can be placed into three life history modes, based mainly on spawning style and time and developmental intervals of larvae at first feeding. Fish in each group may be able to take advantage of floods if the timing is right and prey are plentiful, however, the larvae of some species are able to recruit under non-flood conditions within the main river channel. This forms the basis of the 'low flow recruitment hypothesis', which attempts to explain why some species spawn during the warmest months and lowest flows and how they are able to recruit under these conditions. This hypothesis is then placed in the context of knowledge of the relationships between flow and the biology of Murray-Darling fishes, specifically cues for spawning, movement and recruitment. The lack of widespread evidence for floodplain use by any life history interval of fish may be due to a paucity of study, however, there are some fundamental factors, such as the predictability of timing and duration of high flow events as well as the lack of coincidence of high flows and high temperatures in some regions of the Basin, which may be important in determining the use of floodplain habitats by fish (Humphriesa et al., 1999).

7.2.2 Determining and Managing Environmental Flows for the Shoalhaven River

Every river system has an individual or "signature" flow regime with its own characteristic flow quantities, seasonal flow patterns, and cycles of flood and drought, with these flow characteristics having influences on river flora and fauna and key physical processes such as sediment transport. For example, the graph shows in Figure 16, the historical sequence of total annual flows for the Shoalhaven River at Tallowa Dam. It can be seen that there are many years that are much lower or much higher than the average, showing how changeable flows are in this river system. Many native flora and fauna species will be dependent on this natural flow variability for their survival. Once the flow characteristics for a particular river have been identified, they can be used to develop an E-flows regime that will meet both the needs of river ecosystems and water and river use requirements. (NSW Government Department of Natural Resources, 2006)

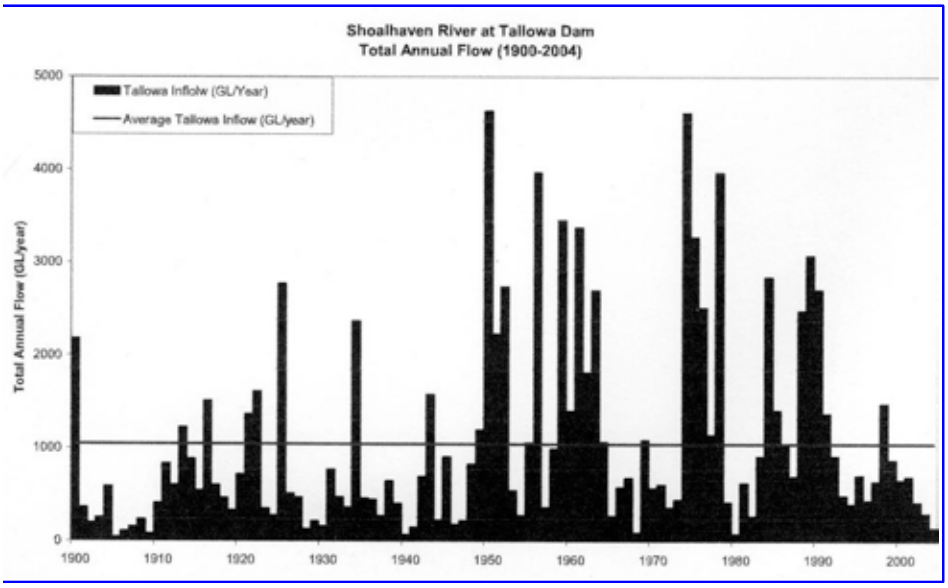


Figure 16: Shoalhaven River total annual flow (1990 – 2004) at Tallowa Dam 1 GL = 1 gigalitre = 1,000,000,000 litres (after NSW Government Department of Natural Resources, 2006)

Many studies have been carried out to determine and managing the E-flows for the river such as the holistic approach to the investigation of E-flows requirements, hydrologic flow analysis and modeling, ecological and physical investigations, and cultural heritage, social and economic assessments, A range of E-flows arrangements have been analysed using the methods analysing and modeling the flow regime for critical flow, measuring flow magnitude and duration components, climatic variability, and flood frequency analysis. Once the critical flow components of the natural river flow regime have been identified, various E-flows arrangements were assessed against the natural flow regime to determine which of the arrangements offer the greatest benefit for the river. (NSW Government Department of Natural Resources, 2006)

Table 3 presents in summary the shortlisted range of environmental flow rules which have the best hydrologic outcome in terms of minimising flow changes downstream of Tallowa Dam compared to the natural flow patterns. The E-flows rule can either allocate more water to the low flows, or alternatively allocate more water to the moderate flows or freshes.

Table 3: Shortlisted range of environmental flow rules (after NSW Government Department of Natural Resources, 2006)

Environmental Flow Rules	**RFO 2** **Protect natural low flows**	**RFO 3** **Protect or restore of a portion of moderate flows, freshes and high flow**	**RFO 6** **Maintain or mimic natural flow variability**	**RFO 11** **Contingent Flows**	**RFO 12** **Maintain or rehabilitate estuarine processes and habitats**
Current Rule	100 % protection of flows up to 90 ML/day.	Not protected above 90ML/day.	100% of inflows only up to 90 ML/day, and then after dam spills	Continued capacity to provide flows to meet contingencies will remain part of the operation of Tallowa Dam	Currently no protection of freshes
Active Environmental Flow **Rule Set 1**	100 % protection of flows up to 150 ML/day.	Protect 30% of incoming flows above 150 ML/day.	100% of inflows up to 150ML/ day, plus 30% of inflows above 150 ML/day.	Continued capacity to provide flows to meet contingencies will remain part of the operation of Tallowa Dam	Objective will be achieved through rules set to achieve RFO 6 and possibly RFO 11
Active environmental Flow **Rule Set 2**	100 % protection of flows up to 250ML/day.	Protect 20% of incoming flows above 250 ML/day.	100% of inflows up to 250 ML/day, plus 20% of inflows above 250 ML/day.	Continued capacity to provide flows to meet contingencies will remain part of the operation of Tallowa Dam	Objective will be achieved through rules set to achieve RFO 6 and possibly RFO 11

[Notes: RFO - River Flow Objectives; RFO 2 - Protect natural low flows; RFO 3 Protect or restore a portion of freshes and high flows; RFO 6 - Maintain or mimic natural flow variability in all rivers; RFO 11 Ensure that the management of river flows provides the necessary means to address contingent environmental and water quality events; RFO 12 - Maintain or rehabilitate estuarine processes and habitats.]

7.2.3 Environmental Water Requirements for Ansons River, Tasmania

The Environmental Water Requirements was carried out using a rapid assessment technique (a rapid desktop approach) and includes flow trigger levels. In order to determine an accurate and defensible flow recommendation, it is generally accepted that the collection of field data is necessary. However this rapid assessment approach is useful for understanding the suitability of the current flow in protecting biota particularly if it is based on the results of full studies. For example Tennant (1976) compared results of a number of full field studies in a particular geographic area. He established that for similar rivers there was an approximate similarity in the percentage of the average annual flow that was required as the survival (10% of the average flow), minimum (30%) or optimum (60%) flow.

Figure 17 shows the map of Ansons River.

Figure 17: The map of Ansons River (after Pinto and Graham, 2000)

Graham et al. (2000) reviewed estimates of the low risk category Environmental Water Requirements in terms of percentile flows. Examining the percentiles of average monthly flows, the Environmental Water Requirement estimates fell in the range of <10% to 30% region of monthly flows. This result suggests that for rapid desktop assessment, low risk Environmental Water Requirements can be set at the 30 percentile of the natural flow estimates of monthly flows. To provide a trigger for review of these Environmental Water Requirement estimates the 35 percentile flows have been adopted.

Using the desktop method, the estimated Environmental Water Requirements (EWR) flows and associated trigger levels for each month for Ansons River are as shown in Table 4. Values are in cumecs and megalitres.

Table 4: Monthly Environmental Water Requirements and trigger levels for Ansons River (after Pinto and Graham, 2000)

	December	January	February	March	April
E.W.R. (cumec)	0.36	0.19	0.10	0.19	0.18
Trigger (cumec)	0.40	0.21	0.13	0.19	0.19

	December	January	February	March	April
E.W.R. (Ml)	31.1	16.42	8.64	16.42	15.55
Trigger (Ml)	34.56	18.14	11.23	16.42	16.42

Some of the known ecological values identified for the catchment are:

- To maintain fish stocks, including Australian Grayling (Prototroctes maraena), Southern pygmy perch (Nannoperca australis), spotted galaxiid (Galaxias truttaceus), jollytail (Galaxias maculatus), freshwater flathead (Pseudaphritis urvillii) and brown trout (Salmo trutta).
- To maintain rearing and/or spawning habitat for Australian Grayling (Prototroctes maraena), Southern pygmy perch (Nannoperca australis), jollytail (Galaxias maculatus), spotted galaxiid (Galaxias truttaceus), brown trout (Salmo trutta), pouched lamprey (Geotria australis), freshwater flathead (Pseudaphritis urvillii), and shortfinned eel (Anguilla australis) and longfinned eel (Anguilla reinhardtii).
- To maintain sufficient habitat for macroinvertebrate populations found in Ansons River.

7.3 Studies on Environmental Flows in China

The River Health and Environmental Flow Project was undertaken 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 subprojects. Three sub-projects were pilot studies incorporating field assessments across three different river basins – the Pearl, Yellow and Liao River basins. (Speed et al., 2012)

The location of the three basin is shown in Figure 18.

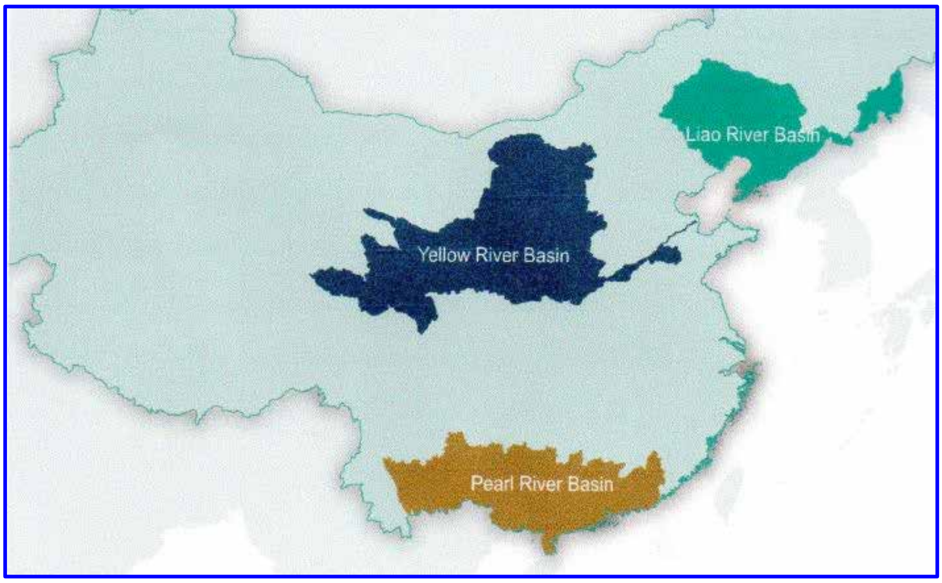


Figure 18: Map showing the location of the three pilot river basins (after Speed et al., 2012)

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 (Speed et al., 2012). The project proposes a national environmental flows framework shown in Figure 19. The framework identifies the elements of a national system for determining E-flows requirements and for incorporating those within allocation and management arrangements. (Speed et al., 2012)

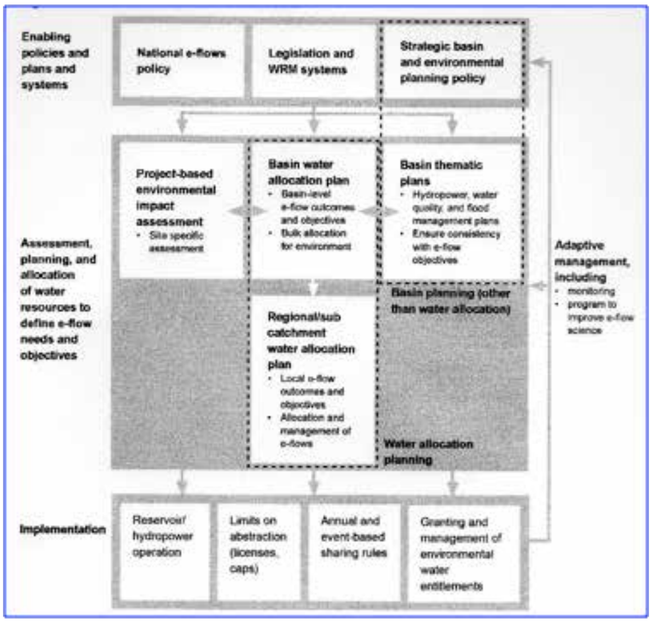


Figure 19: China national environmental flows framework (after Speed, 2012)

7.3.1 The Huang-Ho River Basin (Yellow River)

The Huang-Ho River Basin (Yellow River) is one of the major rivers in China, with the total length of 5464 km, an area of almost 800,000 km^2, a population of over 156 million, and an annual flow of 70 km^3, average annual precipitation 452mm, average annual runoff 53.5 b m^3, groundwater 11 b m^3 annual sediment load 1.6 billion ton and sediment concentration 35kg/m^3 (after Liu Xiaoyan, n.d.).

The river has nearly reached the level of complete water resources exploitation and can be defined as an area in crisis both for people and nature. The water utilization rate in the Huang-Ho River is about 90% of the available water. The duration of low flow periods in the river has increased from forty days in early 1990s to two hundred days in 1997. As reflected in Figures 5 and 6, reserving even a bare minimum of 25% of total flow for the environment brings the basin to the level of absolute water scarcity with a water stress indicator exceeding 1 (after Smakhtin, et al., 2002, in Lim, C.H. & Roseli, 2009).

The E-flows requirement project undertaken from August 2009 until March 2012 applied the assessment method to the lower Yellow River. 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. (International Water Centre, n.d.)

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. (International Water Centre, n.d.)

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 achieving the hydraulic objectives, such as watering important wetlands and providing fish habitat. (International Water Centre, n.d.)

Step 4: Develop preferred E-flows rules. Flow rules were set based on achieving the management objectives. Two E-flows options were developed: one has a low risk for achieving good river health and the other has a medium risk. (International Water Centre, n.d.)

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 E-flows 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.

The pilot study followed a generic E-flows assessment framework developed as part of the project and shown in Figure 20. 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 (Speed et al., 2012).

The Yellow River has ecological assets in the form of important species and communities of waterbirds, fish, macroinvertebrates and plants, plus the ecosystem functions that support them. The lower Yellow River was divided into four reaches, for the study 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 were collected specific to these reaches. Figure 21 shows the lower Yellow River's four reaches and its key ecological assets.

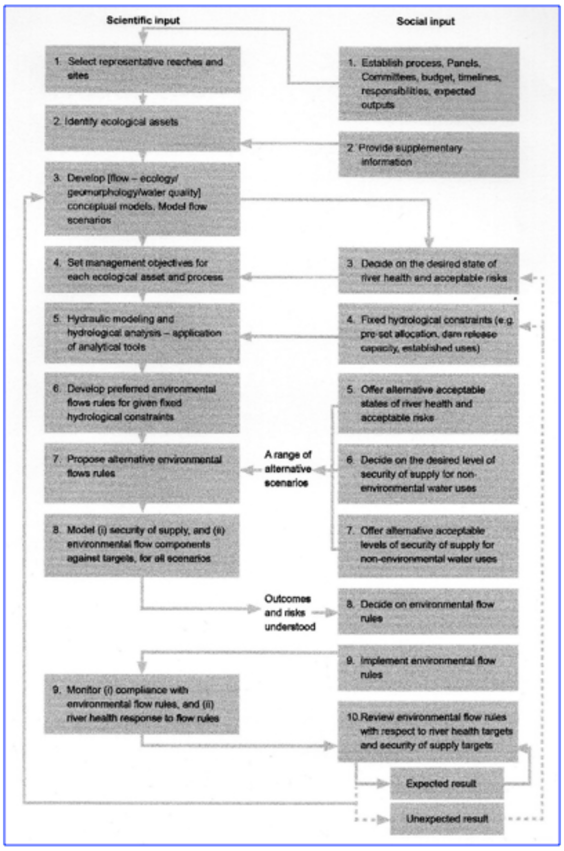


Figure 20: Generic environmental flows assessment method (after Speed et al., 2012)

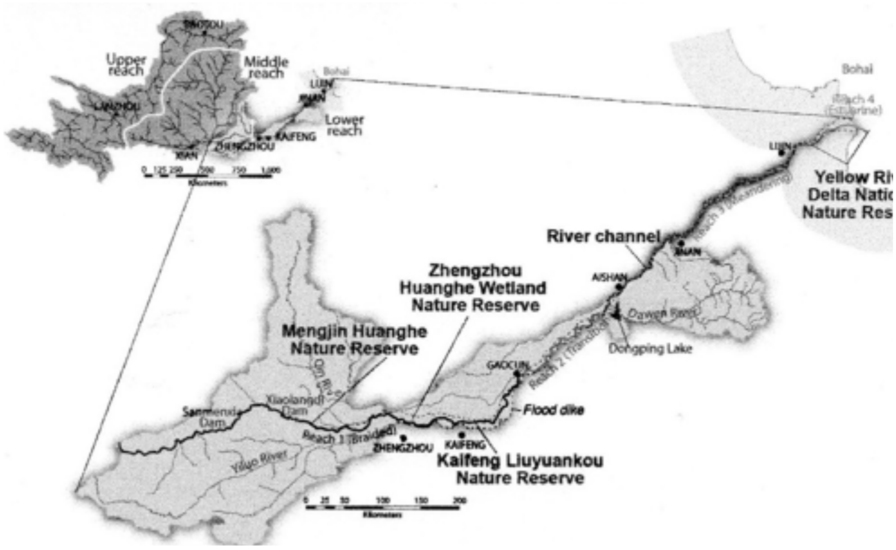


Figure 21: Lower Yellow River basin, showing the four reaches and key ecological assets (after Speed et al., 2012)

Table 5 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. The project has been designed to provide scientific support for the benefits of E-flows, so management decisions can be made with greater confidence. (Speed et al., 2012)

Table 5: Low-risk environmental flow regime for Reach 1 of the lower Yellow River. Huayuankou is the compliance point (after Speed et al., 2012)

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 ≥ 54	Continuous	≥75% of the time	Jun - Nov
V3; V4; F10	Low flow pulse	Jun ≥ 434 Jul ≥ 783 Aug ≥ 1,137 Sep ≥ 1,124 Oct ≥ 866 Nov ≥ 54	≥ 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

7.4 Mekong River Basin

The Mekong River, a trans-boundary river is a vital resource that shapes the social, economic, cultural and ecological functions of the six countries through which it flows; China, Myanmar, People's Democratic Republic of Lao (Lao PDR), Thailand, Cambodia, and Vietnam. With a total catchment area of about 795,000 km^2 and about 4,800 km long, it is one of the largest rivers in the world. Similar to other tropical river systems, the Mekong River has large fluctuations in seasonal discharge. It experiences very low flows during the dry season, yet floods extensively during the rainy season. The most important event of this wet season is the annual flooding of the Tonle Sap in Cambodia, Southeast Asia's largest natural freshwater lake. During this period, the lake expands to five times its dry-season size, allowing fish to move into the wetlands to feed and breed, creating one of the most productive, diverse, and biologically rich freshwater ecosystems in the world. (Hijri and Davis, 2009)

The river provides livelihoods to people in the basin, primarily through fisheries and irrigation. Wild fisheries are the major source of low-cost and high-quality protein, and a major source of employment and income in rural areas. Wetlands that are vital for maintaining the fisheries depend on the cycle of dry-season low flows and wet-season floods to sustain the ecological systems. Rice, the major agriculture product, also depends on flood recession agriculture. The Mekong riparian countries have different economic and social development goals, some of which depend on maintaining existing flows, while others require changes to the flow regime.

The World Bank was the implementing agency for the Global Environment Facility (GEF) Water Utilization Project (WUP), which provided assistance to the Mekong River Commission (MRC) to implement some provisions of the agreement (World Bank, 2000, in Hijri, R. and Davis, R., 2009). An environmental flows approach was developed and applied as the technical basis for determining acceptable minimum flows in support of the procedures enabling Article 6 of the Mekong Agreement, which requires (1) that dry-season flows should be "not less than the acceptable minimum monthly natural flows during each month of the dry season," and (2) wet-season flows should "enable the acceptable natural reverse flow of the Tonle Sap to take place." The WUP aimed to establish interim flow procedures. In addition, the project supported strengthening of various institutional (regional and national) capacity for the implementation of the procedures for water utilization, undertaking basin management functions, coordination with upper riparian and donor agencies, supervision and monitoring of the implementation of the project, and financial and procurement management. (Hijri, R. and Davis, R., 2009)

A three-phase work plan to a work program jointly developed and implemented by the MRC's WUP and Environment Program (EP) entitled Integrated Basin Flow Management (IBFM). IBFM is the MRC's custom-made environmental flows assessment approach to provide information to Mekong basin countries so that more informed trade-offs can be made between development and social and environmental impacts. The three IBFM phases can be summarized as follows (Hijri, R. and Davis, R., 2009):

1. An initial phase designed to describe the present day flow regime of the Mekong basin, make this information readily available, and propose flows based on these as a first step in agreeing acceptable minimum flows.
2. A rapid, yet comprehensive, environmental flows assessment encompassing not only the biophysical, but also the social and economic aspects of possible infrastructure development, based on available data and information with an international recognized panel of experts paired with riparian specialists.

3. On-going comprehensive flows assessment based on continuing field work, acquisition of data and information, and broad stakeholder participation.

Some of its findings from the second-phase include (Hijri, R. and Davis, R., 2009):

1. The Tonle Sap is highly vulnerable to potential flow changes. The high-development scenario has the potential to permanently flood more than 50 percent of the flooded forests that circle its dry-season extent, thereby drastically reducing what is thought to be the main food source for the fishery.
2. The expected benefits of controlling salt intrusion in the Mekong Delta from higher HEP-generated low flows in the dry season would be extremely modest because the extra water flowing down the Mekong would retard draining of the Tonle Sap, and so very little extra water would arrive in the delta.
3. The study also illustrated the shift in beneficial uses of the Mekong's waters by country that would occur as development progressed. Dam building countries would increase their proportion of benefits, while those relying on the natural resources of the river would decrease theirs.
4. The initial economic valuation of beneficial uses, although considered to be only a first approximation, provided indications of the magnitude and direction of change and is considered to be a useful basis to start the discussion of trade-offs between sectors and between regions as the MRC seeks to guide future development activities in the basin.
5. Additional aspects of the flow regime should be considered beyond the two nominated in Article 6 of the Mekong Agreement. They include: (a) vegetation in protected areas in southern Lao and northern Cambodia; (b) bank erosion between Vientiane and Pakse; and (c) maintenance of deep pool habitats for the highly productive and important Mekong fisheries.

Lessons learnt from the studies (Hijri, R. and Davis, R., 2009):

1. The term "environmental flows" can be misunderstood to mean the protection of the environment at the expense of development and human needs. This can bias development agencies and the private sector against the concept to the point where the EFA is ineffective. Technically thorough and scientifically credible EFAs are not sufficient to bring about decisions and implementation of flows for truly sustainable development if there is not strong political and senior managerial support. This is especially true for trans-boundary rivers, where there is a need for trust among the riparian countries, along with technical competence and a mandate for decision by the trans-boundary authority.
2. The Mekong Agreement included the maintenance of just two components of the flow regime: minimum dry-season flows and sufficient wet-season flows to reverse flows into Tonle Sap. The subsequent analyses showed that this was too simplistic and that a wider range of flow components needed to be considered in the full third phase analysis. For example, the establishment of a minimum dry-season flow may be too simplistic: upstream developments that increase dry-season flows may be just as environmentally disruptive as development that reduces dry-season flows.
3. The integration of environmental issues with social and economic development was central to the acceptability of the IBFM program; an analysis that was focused just on environmental outcomes would not have been accepted.

4. A broadly based E-flows assessment using participatory methods in the member countries is highly complex and difficult to communicate in a multinational context. Adequate time and mechanisms are required to communicate and enable understanding of the enabling aspects of the approach, and ownership and mutual benefits by all participants.
5. A phased approach can be effective in establishing EFAs when there is limited expertise and few data available. Interim flow management assessments can be developed and established while skills are developed and data needs are identified and met.
6. Developing a stakeholder consultation process, including the production of information in multiple languages, in trans-boundary river basins where there are major differences in government attitudes toward inclusion and generally a low level of education is extremely difficult and slow. Technical studies, with only limited stakeholder engagement, may be a sensible interim step while a properly inclusive study is developed.

8. Conclusions

E-flows are the water regime provided within a river, wetland or coastal zone to maintain ecosystems and their benefits where there are competing water uses and where flows are regulated. E-flows provide critical contributions to river health, economic development and poverty alleviation. They ensure the continued availability of the many benefits that healthy river and groundwater systems bring to society. (IUCN, 2003)

1. Environmental flows are needed by adapting and managing flow to meet the needs of both people and nature through integration of knowledge across numerous disciplines as law, policy, economics and ecology.
2. Environmental flows are not a simple minimum flow for a river, but instead a means of integrating multiple needs into allocation and flow decisions for rivers, and is thus an important tool for sustainable environment development.
3. There is a need to carry out river restoration programs, rivers back to nature such as using making space for water approaches, enhancement of natural ecosystems thus environmental flows may be obtain naturally.
4. Nowadays as technology advances, the whole spectrum of environment flow should be considered as ‘ecosystem flow’ incorporating low flow, high river flow and above bankfull flow (overbank flow) for different river ecological role as shown by Table 1 rather than just concentrate on compensation flow or low flow.

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http://www.nature.org/initiatives/freshwater/misc/art16857.html Environmental Flow Prescriptions

Appendix A

The Checklist on the Application of Environmental Flows in River Basin Management
– (reported in IUCN, 2008 based on finding from workshop)

Checklist 1: Understanding Flow Requirements, Setting Up Environmental Flow Applications

1. Identify expertise – needed and available
2. Collate existing data and establish data collection
3. Create a data centres – a data management system and library
4. Conduct training and build capacity – build multi-disciplinary teams
5. Develop and start implementing a research programme
6. Conduct pilot studies
   - select method, based on problems, resources and goals
   - data acquisition and analysis
   - knowledge sharing and social learning
   - monitoring

Checklist 2: Setting Objectives / Working with Scenarios

1. Generate scenarios for the river
2. Analyze river flows under each scenario
3. Analyze the ecological, social and economic impacts of alternate flow regimes
4. Use evidence in making / negotiating choices and trade offs
5. Incorporate choices of flow thresholds into development planning

Checklist 3: Modifying Management Infrastructure

1. Review all alternatives to the current operation of the dam or abstraction / or for design and operation of new dams
2. Conduct feasibility studies and environmental and social impact assessments. Develop recommendations
3. Inform stakeholders and the public; facilitate debate on options
4. If there are feasible and acceptable options, develop detailed engineering design, mobilize finance and undertake approval processes
5. Implement new management and undertake monitoring

Checklist 4: Understanding Costs and Benefits / Covering the Costs

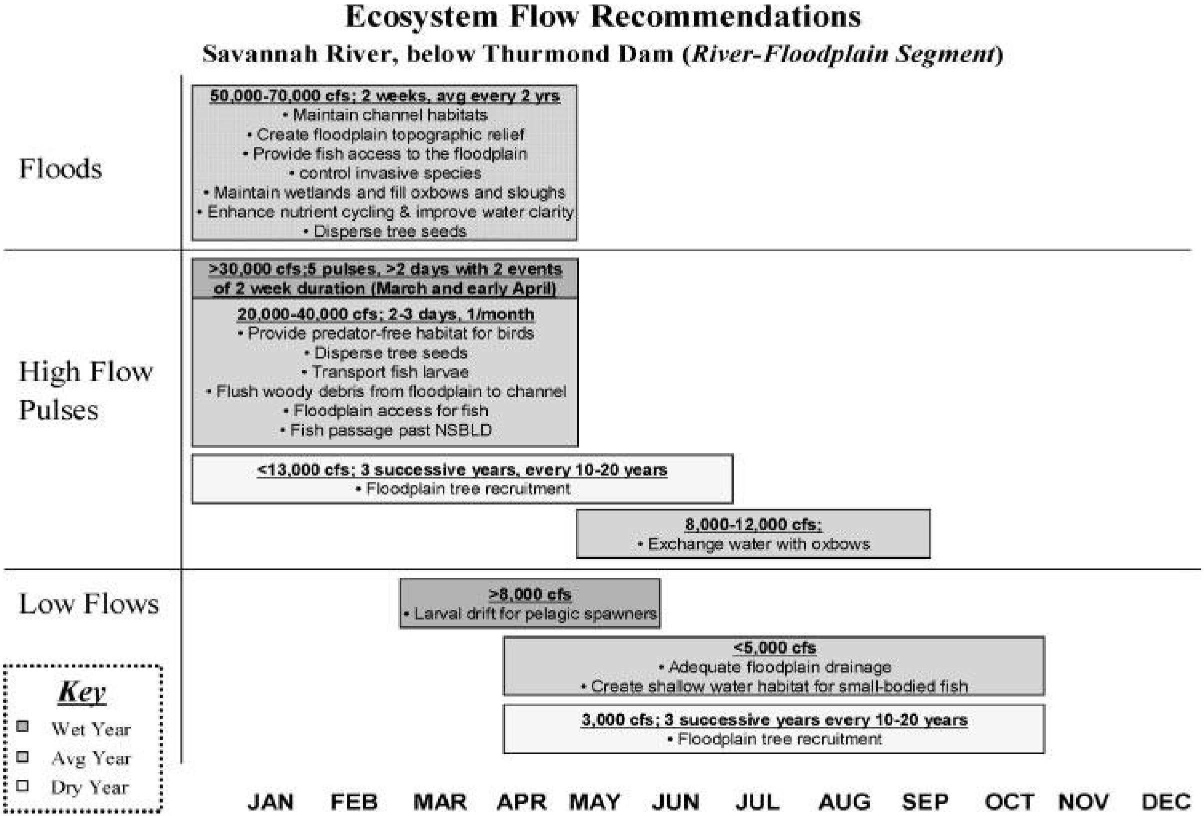
1. Develop clear conceptual and empirical understanding of full economic costs and benefits.
2. Determine if action is justified. If yes, is there a financial gap that needs to be covered?
3. Assess financing needs. What costs need to be covered for adapting infrastructure? Is it socially and environmentally acceptable?
4. Determine which stakeholders bear the costs.
5. Develop incentives and trading mechanisms for covering costs and changing behavior.

Checklist 5: Elements of Reform Processes – Policy, Legal and Institutional

1. Review current policies and legislation, including hard and soft law. Identify entry points in national and international processes (e.g. in strengthening national planning for IWRM, transboundary cooperation agreements). Find basis for engagement in current policies and law. Capitalize on existing processes.
2. Review institutional setup, including mechanisms for implementation and monitoring.
3. Properly define the EF concept – in legal, technical and practical terms. Seek input from technical experts, then influence policy processes in legislatures. Ensure all water users and sectors are well-informed.
4. Incorporate public dialogue into reform processes, through 'socialisation' of concept and communication of practical meaning. Learn from practical pilots and testing. Support social learning. Facilitate civil society input into legislative reforms. Facilitate input and participation in planning.
5. Identify opportunities for transboundary alignment among all riparians. Align bottom- up and top-down processes.
6. Integrate EF and water management into wider policies, law and institutions relating to development in a basin.
7. Consider institutional set-up that will enable implementation of policies and laws.
8. Draft laws and policies and review.

Appendix B

Developing Environmental Flow Recommendations (Richter et al. 2006)



This diagram highlights some of the key ecological objectives to be supported by the flow recommendations developed for the Savannah River floodplain segment. These objectives pertain to specific flow components (low flows, high flow pulses and floods), time of year, and water year type (dry, average, wet)

Appendix C

Methods of Determining Environmental Flows (as explained in DID, 2009)

In general, the methodologies can be grouped into four categories:

1. Hydrological Methods;
2. Hydraulic Methods;
3. Habitat quality methods; and
4. Holistic methods

1. Hydrological Methods

Simplest of all, hydrological methods as typically a desktop methodology, are based on the use of the hydrological data, usually in the form of historical monthly or daily flow records. This methodology is considered to be the most appropriate at the planning level of water resource development.

These are the simplest and most widespread E-flows methods. They are often referred to as desktop or look-up methods and they rely primarily on historical flow records. E-flows is usually given as percentage of average annual flow or as a percentile from the flow duration curve, on an annual, seasonal or monthly basis. Most methods simply define the minimum flow requirement, however, in recognition of the 'Natural Flow Paradigm' more sophisticated methods have been developed to take several flow characteristics into account (such as low- flow duration, rate of flood rise/fall, etc.).

Hydrological Index Methods provide a relatively rapid, non-resource intensive, but low- resolution estimate of E-flows. The methods are most appropriate at the planning level of water resources development or in low controversy situations where they may be used as preliminary estimates.

The most frequently used methods include Tennant Method (Tennant, 1976) and RVA (Range of Variability Approach) (Richter et al, 1997) both developed in the USA. The Tennant method was originally called the 'Montana Method' by Tennant because it was created using data from the Montana region and was developed through field observations and measurements. Tennant collected detailed cross-section data that characterized different aspects of fish habitat. These include width, depth, velocity, temperature, substrate and side channels, bars and islands, cover, migration, invertebrates, fishing and floating, aesthetics and natural beauty. These metrics were related to a qualitative fish habitat quality. This allowed for a determination of discharge to fish habitat through the correlation of physical geometric and biological parameters to discharge.

Tennant (1976) then related percentile of the average flow would relate to fish habitat qualities and produced an easy-to-apply standard that can be used with very little data. The technique utilizes only the average annual flow for the stream. It then states that certain flows relate to the qualitative fish habitat rating that is used to define the flow needed to protect fish habitat, i.e. the quality desired.

The Tennant method is considered a standard setting method, meaning that it uses a single, fixed rule as a minimum baseflow. This means that it is easily applied to any situation without collecting an abundant data or being expensive.

2. Hydraulic Methods

Hydraulic approaches use changes in simple hydraulic variables, such as wetted perimeter or maximum depth. It is usually measured across single, limiting river cross-sections, as surrogate for habitat factors known or assumed to be limiting to target biota.

The most commonly used hydraulic rating methodology worldwide today is the generic wetted perimeter method. Basic assumption is that river integrity can be directly related to the quantity of wetted perimeter. The wetted perimeter is the length of stream bottom substrate that is wet along a cross section oriented perpendicular to the river. E-flows are calculated by plotting the variable of concern against discharge. This produces a curve of the relationship between discharge and wetted perimeter that can be analyzed for the breakpoint or inflection point. Commonly, a breakpoint, interpreted as a threshold below which habitat quality becomes significantly degraded, is identified on the response curve, or the minimum E-flows is set as the discharge producing a fixed percentage reduction in habitat. There is an on-going discussion about how the breakpoint should be defined, and this is the main disadvantage of this method.

3. Habitat Simulation Methodologies

The habitat simulation methods attempt to determine E-flows on the basis of detailed analyses of the quantity and suitability of instream physical habitat are available to target species under different discharge (flow regimes). Typically, the flow-related changes in physical microhabitat are modelled in various hydraulic programs, using data on one or more hydraulic variables collected at multiple cross-sections within the river study reach. The simulated available habitat conditions are linked with information on the range of preferred to unsuitable microhabitat condition for target species, life stages, assemblages and/or activities, often depicted using seasonally defined habitat suitability index curves. The resultant output usually in the form of habitant-discharge curve for the biota, or extended as habitat time and exceedence series are used to predict optimum flows as E-flows.

Physical Habitat Simulation System (PHABSIM) is one of the commonly used instream flow models. PHABSIM uses four hydraulic criteria that are calculated from field measurements and related to fish habitat quality. The hydraulic variables included in the model are water depth, flow velocity, substrate and cover (Gillilan and Brown, 1997). The required field data include cross-section survey. The outputs of PHABSIM are weighted usable area (WUA) curves that relate discharge to a fish habitat index for different life stages of fish species of interest and habitat guild (Waddle, 2001).

One of the most complete methods from this group is Instream Flow Incremental Methodology (IFIM), developed by the U.S. Fish and Wildlife Services. In IFIM, the investigator examines more than a snapshot of the microhabitat characteristics of the stream to determine minimum flow. IFIM also considers micro habitat characteristics like stream temperature and water quality along the stream channel (Gillilan and Brown, 1997). IFIM also tends to be used to determine the effect of an activity on habitat, and in restoration situations once the effect of the activity is better understood (Gordon et al., 1992). Users within the U.S. Fish and Wildlife Service found IFIM to either be too complicated to apply (too expensive, not trained well enough, or took too much time), or too simplistic (models or curves needed improvement).

4. Holistic Methods

Holistic methods are actually frameworks that incorporate hydrological, hydraulic and habitat simulation models. They are the only E-flows methodologies that explicitly adopt a holistic, ecosystem-based approach to E-flows determinations.

In recent years, holistic approaches have greatly contributed to the field of E-flows assessment. Doupe and Petitt (2002) believe that in order to determine E-flows it is necessary to find balance between requirements for water in an ecosystem and socio-economic environment that leads to holistic and comprehensive approach for water resources management in open watercourses. In holistic methodology, important and/or critical flow events are identified in terms of selected criteria defining flow variability, for some of all major components or attributes of the river ecosystem. The basis of most approaches is the systematic construction of a modified flow regime from scratch (i.e. bottom-up), on a month- by-month (or more frequent) and element-by element basis, in which each element represent a well-defined feature of the flow regime intended to achieve particular ecological, geomorphologic, water quality, social or other objectives in the modified system (King and Tharme, 1994). In contrast, E-flows are defined in terms of acceptable degrees of departure from the natural (or other reference) flow regime, rendering them less susceptible to any omission of critical flow characteristic or processes than their bottom-up counterparts (Burn, 1998).

The building block methodology (BBM) is being a holistic methodology that addresses the health (structure and functioning) of all components of the river ecosystem, rather than focusing on selected species. BBM remains one of only two methodologies in the world for which a manual has been written (King et al., 2000), the other being IFIM (Milhous et al., 1989). The BBM is presently the most frequently applied holistic methodology in the world. The advantage of the BBM "expert team approach" is its flexibility and consensus building amongst experts who come to the best solution based on the data and model results available. The disadvantage is that it is not necessarily replicable and another group of expert might come to different conclusions.

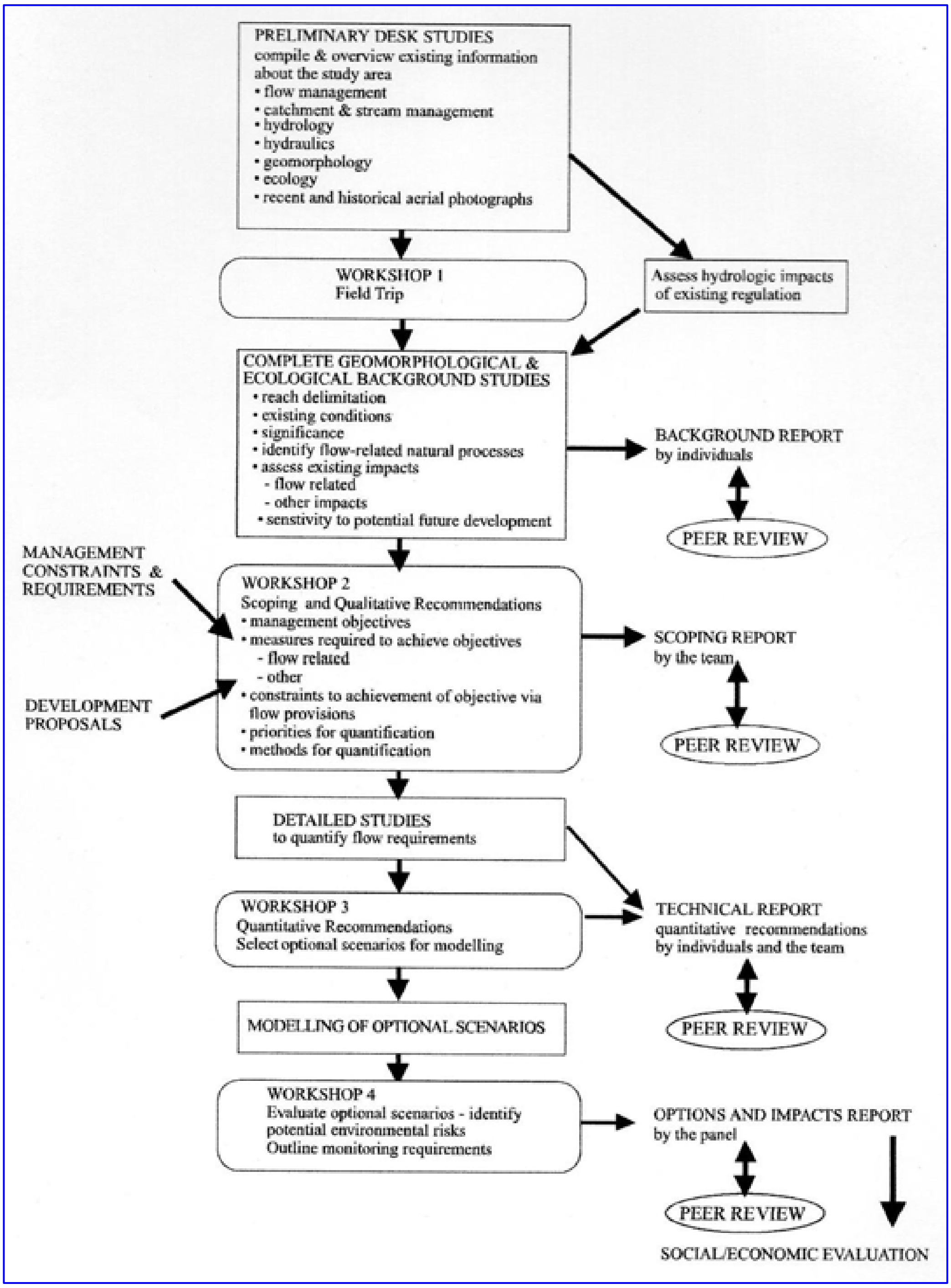
Evolving from the BBM and other similar methodologies as an interactive, top-down holistic methodology comprising four modules (biophysical, social, scenario development and economic), the Downstream Response to Imposed Flow Transformation (DRIFT) process (King et al., 2000) offers innovative advances in E-flows assessment. It focuses on identification, by a multidisciplinary team, of the consequences of reducing river discharges from natural, through a series of flow bands associated with particular sets of biophysical functions, and of specific hydrological and hydraulic character, in terms of the deterioration in system condition. The DRIFT methodology is an interactive, scenario-based approach, designed for use in negotiations, and contains a strong socio-economic component, important when quantifying subsistence use of river resources by the people living in the riparian zone.

Although DRIFT is usually used to build scenarios, its database can equally be used to set flows for achieving specific objectives. Two other activities outside DRIFT provide additional information to the decision-maker:

- A macro-economic assessment of each scenario, to describe its wider regional implications in terms of industrial and agricultural development, cost of water to urban areas and so on; and
- A public participation process, in which the wider body of stakeholders can voice its level of acceptability of each scenario.

Appendix D

Framework for assessing environmental flows in regulated and unregulated river systems (after Arthington and Zalucki, 1998)



Topic 4

Forest Hydrology, Ecosystem and Environmental Water Security

Mobilizing Science for Healthy Ecosystems

Mangrove Forest in Siberut Island,
West Sumatra, Indonesia

Topic 4

Forest Hydrology, Ecosystem and Environmental Water Security

Summary

Asia and the Pacific region is marked by a wide range of geographic and biological diversity. It includes the world's highest mountain systems, the second largest rainforest complex, more than half the world's coral reefs, and a diversity of island systems. Unless immediate, decisive steps are taken to counter the effects of deforestation and other forms of natural resource destruction in Asia and the Pacific region, much of Asia's biodiversity will be irreversibly lost within this generation.

Services provided by forests cover a wide range of ecological, political, economic, social and cultural considerations and processes. This diversity means that there are no easy management solutions, and management is not a technical, mechanical process but one that must necessarily incorporate a variety of competing interest groups and views.

1. Introduction

1.1 There is increased recognition that forest management is needed to maintain forest, ecosystem, and watershed health and resilience. The study of how water flows and recycles through forests, can help illuminate connections between forests and water.

2. Key Challenges and Opportunities in Asia and the Pacific Region

2.1 FAO (2007c) figures indicate that the rate of forest loss has been greatest in Asia with many countries losing more than 1 percent of their forest each year. Economic opportunities, biodiversity and environmental services are being lost and degraded. The challenging issues are: forest degradation, forest fires, forest biodiversity, climate change, bioenergy, forests and poverty reduction, desertification, etc. The challenge is to support specific changes that will increase the benefits of forest and tree resources for poor people, thus enhancing their contribution to the reduction of poverty, especially in rural areas (FAO, 2007b).

2.2 Some of the challenging issues in Pacific Island countries are (Heads of Forestry Meeting, 2003; AusAID, 2006; FAO, 2009): economic and social development, values, governance, land tenure, environmental challenges, etc.

2.3 Asia and the Pacific countries are witnessing major shifts in the overall policy and institutional environment, reflecting larger political and social changes. The trends include greater demands for social justice and participation in governance and in public policy decision-making, increased plurality and wider involvement of civil society and private sector organizations (APFC, 2010).

3. Forest and Oil Palm Hydrology in the Tropics

Tropical Rainforests

3.1 Tropical rainforests are very wet places, receiving heavy rainfall either seasonally or throughout the year. The area is close to the equator and gets lots of sunlight. The average annual rainfall is normally more than 200 cm rainfall per year. Tropical rain forests have large trees that are green year-round due to the consistent levels of rain they receive. This evergreen forest is abundant, inspiring, and a constant source of new scientific discoveries.

3.2 The most important hydrological function of forest is to provide enough and clean water. Forest has the availability to absorb water during rain event, store it and then release it during dry period through its sponge effects. The largest forest function is production, followed by multiple use including sources for community, protection of soil and water, conservation of biodiversity, recreation and education purposes.

3.3 The Selective Management System (SMS) has become a dominant method of commercial logging in the tropical rainforests of the Asia and the Pacific region. It has been recognized that this method minimizes the impact on the forest (Yusop and Suki, 1994) compared to uncontrolled logging. However, because of the limited number of trees harvested, and the slight effect on the growth of unharvested trees, reports have suggested that its damage is potentially serious and not worth the disturbances (Griesier, 1997). Selective logging operations involve road construction, canopy clearance, tree harvesting and skidding, and have increased the percentage of bare soil and impermeable areas within forested catchments.

Oil Palm Agriculture

3.4 Roundtable on Sustainable Palm Oil (RSPO), an international organization of producers, has defined sustainable palm oil production as legal economically viable, environment friendly approaches and socially beneficial management and practices (Tan et al., 2009). RSPO has recently established as set of principle and criteria for the management of oil palm and palm oil mills and encouraged the planters to follow Best Management Practices (BMPs) (Lord and Clay; 2006). These practices are more environmental friendly by using approaches like zero burning for land clearing, conservation of wildlife and habitat, integrated pest management (IPM) and waste minimization and recycling.

3.5 The most contentious environmental issue in oil palm industry is deforestation as huge tracts of tropical rainforest are converted to plantations (Germer and Sauerborn, 2008). Due to increasing international demand on biofuel plus with lack of land and mineral soils has accelerated the conversion of peat land, into oil palm plantations (Sheil et al., 2009; Tan et al., 2009). Moreover, the drainage results in rapid peat subsidence and compaction were led to various changes in its physical properties.

3.6 The methods of site clearing became significant owing to the threats the indiscriminate site clearing like burning poses to the environment and water quality of the plantations in question. The burning method of site clearing poses threat to groundwater. The conversion of peat swamp forests to cropland like oil palm plantations releases CO2 and other GHGs to the atmosphere as a result of fossil fuel burning and microbial decomposition of organic matter stored in the plant and soil biomass which further aggravates climate change. The clearing of the vegetative covers of the peatland exposes the soil to erosion, which further exposes the groundwater to the debris and other harmful substance from soil surface thereby polluting it. According to Tanga et al., (2005), conversion of agricultural forest, grass, and wetlands to urban areas usually comes with a vast increase in impervious surface, which can alter the natural hydrologic condition within a watershed. Consequently, the water quality is eroded and this becomes one of the risks involved in oil palm cultivation as a result of threats to freshwater streams which numbers of local communities depend on for drinking and their livelihood.

3.7 In Malaysia, the recommended practice in the area of site clearing is zero burning policy which has been practiced. All the NGOs such as RSPO, GEC, NAP, and national and international agency like, MPOB, and Wetland International recommended the principle of zero burning as the major method of land clearing prior to oil palm cultivation. This is to avoid peat swamp degradation which affects their hydrological and ecological usefulness while improving on soil fertility. Zero burning policy has been globally encouraged as it poses no threat to both the soil and the environment. (UPM, 2017)

4. Environmental Water Security in Asia and the Pacific Region

4.1 An important step forward is to encourage river health monitoring at the country and basin levels, together with strengthening coordination and cooperation among individual infrastructure projects. According to the study by ADB (2016) the results for environmental water security show that some countries score fairly high while others score quite poorly. Countries that show relatively high scores are in the Pacific. The lowers score are from South Asian countries.

4.2 Linkages to Sustainable Development Goal No. 6 (SDG 6) targets are: (1) By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes; (2) By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally.

4.3 Public and community can also play their role in protecting rivers and its environment such as involved in “let us get to know our rivers” through programme such as carrying out river auditing. The relevant authority(s) in Asia and the Pacific region countries is encourage to monitor river health environmental water security such as by using what is known as “a river keeper’s field book”.

5. FAO on Forests for a Greener Future in Asia and the Pacific Region

5.1 FAO encourage reinvestment in forests as necessary measure to reduce timber import dependence, support biodiversity conservation and climate change mitigation, revitalize rural economies and protect land and populations from environmental hazards and the impacts of climate change.

1. Introduction

Freshwater resources originate on forested lands. Maintaining their functional integrity is fundamental to the sustainability of ecosystems and societies alike. There is increased recognition that forest management is needed to maintain forest, ecosystem, and watershed health and resilience.

Forest hydrology, the study of how water flows and recycles through forests, can help illuminate connections between forests and water. It need to address current complex issues, including climate change, wildfires, changing patterns of development and ownership, and changing societal values (Jones et al., 2009, in Amantya, D.M, et al, 2011).

2. Water and Forests

Food security is dependent on water security and water security is dependent on forests. Approximately 75% of the world's accessible freshwater for agricultural, domestic, urban, industrial and environmental uses comes from forests. Forests and trees are essential to maintaining resilient production systems, communities and ecosystems. They are vital to our water supply, providing high quality water resources: they intercept atmospheric moisture, contribute to cloud and rain formation, reduce erosion and recharge groundwater. However, changes in climate and land-use are contributing to altered groundwater and base flows locally, and precipitation regionally (FAO, 2016).

With approximately 80% of the world population facing water insecurity, the management of forests for water is increasingly important. The relationship between forest and water resources needs to be addressed through integrated management and policies, supported by scientific understanding (FAO, 2016).

Forests act as natural water filters. Forests minimize soil erosion on site, reduce sediment in water bodies (wetlands, ponds, lakes, streams, rivers) and trap or filter water pollutants in the forest litter. Climate change is altering forests' role in regulating water flows and influencing the availability of water resources. Forests are at the forefront of reducing the effects of climate change. In respect of water, one benefit is forests' cooling effect on the environment produced through evapotranspiration and the provision of shade. The impacts of climate change may also be manifested in an increase in catastrophes such as floods, droughts and landslides – all of which may be influenced by forest cover. Moreover, large-scale deforestation can have an impact on precipitation patterns.

When precipitation is generated and rainfall occurs in forest areas, it intercepts on the canopy level, given the high density of canopy, structure of trees with several layers that lowers the energy of rainfall before it reaches the ground. A proportion of rainfall reaches the ground directly as throughfall and small proportion as streamflow. The water that reaches ground infiltrates into the soil until it is saturated and if it continues raining, water is transported to the lower gradient as overland flow. Whereas, in the soil, water continues to flow between the soil particles to the stream as subsurface flow. Some of the water also percolates into deeper layer and recharges soil water. At the soil surface, water is stored as soil moisture and it is evaporated to the atmosphere if it is exposed to sun radiation (UPM, 2017). The proportion of global water balance is shown in Figure 1

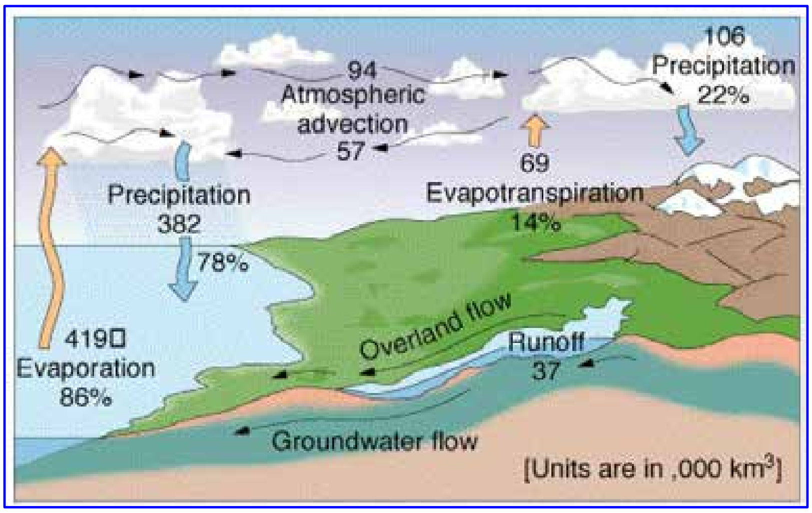


Figure 1: The global water balance and its proportion (source: UPM, 2017)

Hydrological cycle is affected differently by different land uses depending on proportion of vegetation cover, perviousness surface of the area, temperature, etc. For example, the proportion of runoff in urban areas is higher than in forest areas (Figure 2). In contrast, evaporation rates in urban areas is higher than in forest areas. Most developed areas alter natural hydrological cycle as development involves changes to surfaces and drainage systems.

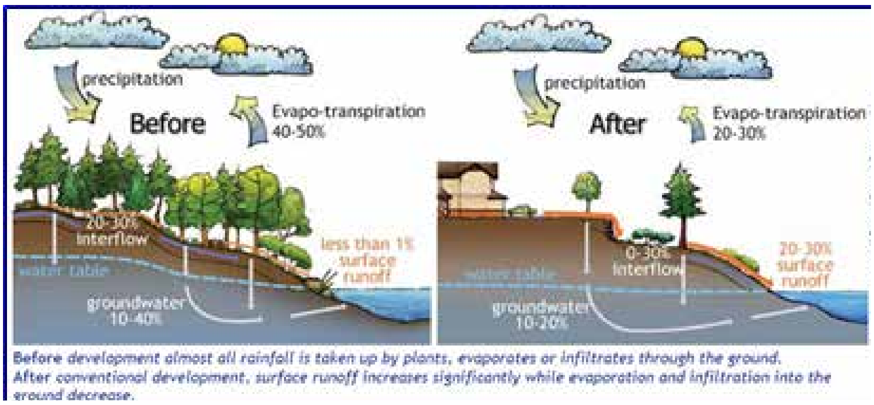


Figure 2: Hydrological cycle and its components changed after development (source: UPM, 2017)

Forests contribute most significantly to the hydrological balance of watershed ecosystems by maintaining high-quality water. This is achieved through minimizing soil erosion on site, reducing sediment in water bodies (wetlands, ponds and lakes, streams and rivers) and trapping or filtering other water pollutants in the forest litter and underwood. Good forest cover is the most effective land cover for keeping water as sediment-free as possible. Forest is certainly the best cover for drinking-water supply watersheds, because forestry activities involve no use of fertilizer, pesticide and fossil fuel or outfalls from domestic sewage or industrial process. The quality of rivers depends on the amount of pollutants entering the water bodies (UPM, 2017).

2.1 Stream Ecology

Streams like springs and rivers are also known as lotic habitat. A lotic habitat and its ecology is primarily characterized by unidirectional flow, constant state of physical change and a high diversity of microhabitats, where the fauna and flora has adapted themselves to the flow conditions. The ecology of lotic habitat is governed by abiotic and biotic factors, the former being flow, light, temperature, chemistry and substrate. Flow is the most influential abiotic component in determining a stream ecosystem as it is responsible for producing riffles, pools and gliders via erosion and deposition (DID, 2009a).

Light is the main source of energy in a lotic environment and is required for primary production which provides the foundation for the trophic web in an aquatic system. Aquatic plants and algae including periphyton (filamentous and tufted algae which clings on rocks) need light for photosynthesis and other animals depend on them as part of the food chain. The varying degree of light available in the water column as well as the stream surroundings also help dictate the community structure of both fauna and flora. Likewise differential temperatures resulting from varying light intensities in a stream affects the biological population in a stream ecosystem. Deeper waters tend to host fish with preference for colder temperature while shallower exposed streams are dominated by species with tolerance for higher temperatures. Stream water temperature usually varies diurnally and for some localities seasonally e.g. lower temperatures are normally associated with wet season and vice versa. Maintaining a good riparian cover along a stream goes a long way in preserving its ecosystem (DID, 2009a).

3. Key Challenges and Opportunities in Asia and the Pacific Region

Asia's forests are very important as they harbor most of the rare and unique plants and animals in the world. In fact, five countries in Asia are included among the "megadiverse" countries — China, India, Indonesia, Malaysia and the Philippines (UNDP, 2006). It has around 40 percent of the world's mangrove forest (IUCN, 2006) and it also supplies many commercial timber tree species. Yet, despite huge potentials, there are many problems and issues in Asia that deal in one way or another with forests.

During the first five years of the twenty-first century, the variation in the net rate of change in forest area among countries in Asia was dramatic. FAO (2007c) indicates that the rate of forest loss has been greatest in Asia with many countries losing more than 1 percent of their forest each year. Economic opportunities, biodiversity and environmental services are being lost and degraded due to problems related to forest degradation and deforestation such as illegal logging, desertification, forest fires and shifting cultivation that contribute to global problems of climate change and global warming, environmental instability, poverty and social conflicts.

3.1 Challenging Forestry Issues in Asia[1]

Some of the challenging issues are:

1. Forest degradation. The amount of degraded Asian forest ecosystems, particularly tropical forests increase each year. Deforestation is the result of the interaction of many environmental, social, economic, cultural and political forces, which vary in different countries. Although the Asian region as a whole experienced a net increase in forest area of about 633,000 hectares annually during 2000 to 2005, the improvement was largely the result of an increase of more than 4 million hectares/year in China (FAO 2007c). Many of the countries, especially in Southeast Asia, experienced a net loss.

[1] This section is primarily drawn from FAO (2009)

In Asia, the agents of deforestation as described by Roper and Roberts (1999), FAO (2009) are commercial farmers, slash-and-burn farmers, loggers, commercial tree planters and infrastructure developers. Among these activities, slash-and-burn or shifting cultivation and logging might be considered as the major contributors to forest degradation in Southeast Asia. Farmers opted for this practice in an attempt to settle farmland for daily subsistence. However, despite the benefits and income it provides, the forest suffers because of the wrong use of its resources, consequently affecting human lives as well. The activities not only decreased the forest area, but also changed the primary forest into secondary shrub woodland. It accelerated soil and gully erosion and acidification as well.

On the other hand, logging, whether legal or illegal, has a major role in deforestation phenomena. It also contributes to loss of biodiversity and forest fires. It is a pervasive problem, causing enormous damage to forests, to local communities and to the economies of producer countries. Rampant deforestation, much of it from illegal logging, has destroyed forests that stabilize soils and regulate river flow, causing record floods and landslides (FAO, 2009).

It is a major challenge to halt many factors contributing to forest degradation or deforestation in the future. There are many opportunities for controlling and minimizing its negative impacts such as include the protection and management of remaining forests, socio-economic development in rural areas and policy and institutional reforms.

2. Forest Fires. According to FAO (2007a, in FAO, 2009), forest fires are increasing as a result of climate change and they are affecting larger areas and becoming more severe in many regions of the world. Fires are common in most deciduous forests in Southeast Asia and the so-called "fire climax" pine forests in Myanmar, Thailand, Lao PDR, Cambodia, Viet Nam, the Philippines (Luzon) and Indonesia (Sumatra) (Goldammer 1997, in FAO, 2009). In Brunei, forest fires occur in coastal heath and beach forests, which experience a long dry season, windy conditions, have high fuel loads and are easily accessible (Hassan and Manila, 1997, in FAO, 2009). Although forest fires have occurred in Southeast Asia for centuries and are an important factor in the development of terrestrial ecosystems, concerns about changes in fire regimes and their impacts are growing (Karki, 2002, in FAO, 2009). Fires started by agricultural activities are serious threats to biodiversity. In Thailand, most forest fires are caused by deliberate or accidental human activities (Samran and Akaaraka, 1997, in FAO, 2009). Arson and the use of fires on agricultural land and for land conversion are major causes of forest fires in Brunei while in Malaysia, negligence and agricultural activities are considered to be the most important causes of forest fires (Hassan and Manila, 1997, in FAO, 2009).

   Policy-makers now realize the importance of fire protection and continued fire management, as emergency response will not prevent large and damaging fires. As a result, sustainable forestry practices, improving agricultural burning practices and promotion of better regional cooperation in forest fire control are the strategies being used at present (Asia Forest Partnership, 2004, in FAO, 2009).

3. Forest biodiversity. Forests are among the most important pools of terrestrial biological diversity. Together, tropical, temperate and boreal forests offer diverse habitats for plants, animals and other life. Forest biological diversity is needed to allow species to continuously adapt to changing environmental conditions, to maintain the potential to meet human needs and to support ecosystem functions (FAO, 2009).

Deforestation is causing the foremost loss of biological diversity on a large scale. Although tropical forests cover only 6 percent of the earth's land surface, they contain between 70 and 90 percent of all of the world's species (Myers 1991, in FAO, 2009). These tropical forests areas of high importance for biodiversity are situated mostly in the world's least developed countries.

4. Climate Change. Although all the effects of deforestation are potentially serious, perhaps the most alarming is that of climate change due to the loss of trees. In the absence of trees, global warming worsens, as there is nothing to absorb the continuous emissions of CO_2 and other forms of gas, the products of different human activities. Global carbon dioxide emissions continue to rise, with the world producing 16 percent more in 2003 than 1990, according to the World Bank (2007, in FAO, 2009). Most of the polluted areas are in the developing countries, which contribute as well to emissions in the atmosphere.

5. Other Forestry Issues includes: bioenergy, forests and poverty reduction, desertification etc. Wood energy is the dominant source of energy for over 2 billion people, particularly in developing countries. Fuelwood and charcoal are absorbing around 60 percent of worldwide wood removals, a share that rises to over 80 percent in developing countries, putting considerable pressure on forests and trees (FAO, 2009).

   The World Bank (2001, in FAO, 2009) estimated that 1.6 billion people depend to varying degrees on forests for their livelihoods, with 350 million living in or near dense forests depending on them "to a high degree." The challenge is to support specific changes that will increase the benefits of forest and tree resources for poor people, thus enhancing their contribution to the reduction of poverty, especially in rural areas (FAO, 2007b).

   Desertification is the degradation of land in arid, semiarid and dry sub-humid areas. It is caused primarily by human activities and climatic variations. It occurs because dryland ecosystems, which cover over one-third of the world's land area, are extremely vulnerable to overexploitation and inappropriate land use. Poverty, political instability, deforestation, overgrazing and bad irrigation practices can all undermine the land's fertility (FAO, 2009).

3.2 Challenging Forestry Issues in Pacific Island Countries (PIC)[2]

Some of the challenging issues are (Heads of Forestry Meeting, 2003; AusAID, 2006; FAO, 2009):

1. Economic and social development. Economies need to grow at a faster rate in order to effectively address their pressing development needs. Good management and wise investment in people and their natural resources are vital for sustainable economic performance.

2. Values. The tremendous varieties cultures display a common trait of communal sharing and the recognition of communal rights over individual human rights. Cultural obligations can be difficult to overcome when there are temptations to favor extended family members or one's own tribal needs over others.

3. Governance. It has been identified that governance in all sectors - private, civil society as well as government - has emerged as an issue of widespread concern. A UNDP assessment for example, reasoned that poor growth has been primarily a result of internal factors including adverse political developments, poor macroeconomic management, corruption and poor governance (UNDP, 2006, in FAO, 2009). Mismanagement and lack of resources in government, forestry authorities undermine well-formulated codes of logging

[2] TThis section is primarily drawn from FAO (2009).

practices. It was reported that some countries sustainable forest management was nowhere being achieved not because of lack of knowledge but the inability to apply it. An additional issue of forest governance that concerns all PIC communities is the rapid loss of traditional knowledge, local culture and customary appreciation of forests and native trees.

4. Land tenure. "No subject in the Pacific is more contentious than land" (AusAID, 2006, in FAO, 2009). Landholding in the Pacific is largely communal under a customary ownership system with some alienated land now either owned by the government, or privately owned under freehold titles. In some countries communal land is not officially registered, so disputes over ownership are common and investment is often delayed while land cases are settled in court. Communal landownership poses a challenge for planning and management of a nation's forest cover and allocation of the range of forest land uses including sustainable logging, sustainable subsistence use, protection forest and conversion to plantation forest.

5. Environmental challenges. Emerging environmental issues of importance in PICs include: rapid loss of biodiversity due to degradation of both terrestrial and marine environments; waste management and pollution; natural disasters exacerbated by global warming and extreme climate change.

3.3 Policy and Institutional Issues

Past forest policies of Asia and the Pacific countries were driven by two main societal necessities. The first being food security and the second being the quest for revenue. The political and socio-economic priorities of those times when countries strived to maximize their earnings and also ensure adequate food stocks. Conversion of forests into agricultural lands yielded revenue from timber sales and later from levies on agricultural produce (FAO, 2009).

The policies in region are then dominated by the following:

1. Problems of deforestation.
2. Widening the gap between supply and demand of forest products.
3. Environmental considerations - goods and services from forests.
4. Decentralization, devolution and privatization.
5. Forest product needs among rural and forest-dependent communities.

Drivers of future policies which are expected to dominate the forest policies of the Asia and the Pacific region in the near future specially in the next two decades are (FAO, 2009):

1. Increasing demand for timber and industrial wood.
2. Climate change - forests as carbon sinks, and carbon trading.
3. Fuelwood as a carbon neutral energy source.
4. Biofuels.
5. Sustainable forest management.
6. Poverty alleviation.
7. Decentralization and devolution of management to communities.
8. Environmental services from forests.
9. Rights of local communities.
10. Revenue from non-extractive sources.
11. Comprehensive intersectoral planning.
12. Globalization.

The sector development depends on an institutional framework that comprises a number of organizations, public and private, with differing mandates, roles and functions. Within this broad institutional framework, public forest institutions (such as forestry departments and agencies) play many key roles and their performance is crucial for sector development. Yet, the roles of forest institutions are rapidly changing due to changing demands on forests and their governance. Forests are increasingly recognized as key to solving pressing global issues such as climate change, energy scarcity, poverty, environmental degradation, biodiversity loss, food scarcity, and raw material supply (FAO, 2015).

Asia and the Pacific countries are witnessing major shifts in the overall policy and institutional environment, reflecting larger political and social changes. Notable trends include greater demands for social justice and participation in governance and in public policy decision- making, increased plurality and wider involvement of civil society and private sector organizations (APFC, 2010).

4. Forest and Oil Palm Hydrology in the Tropics

4.1 Hydrological Cycle in Tropical Forest Area

Hydrological cycle in tropical forest area by Gilmour (1975) is shown in Figure 3. The hydrological cycle could be altered in terms of proportion of the components depending on the disturbance levels of the forest. Overland flow, for example, is higher in selectively logged forest than in virgin tropical forest, whereas the highest in clear fell forest.

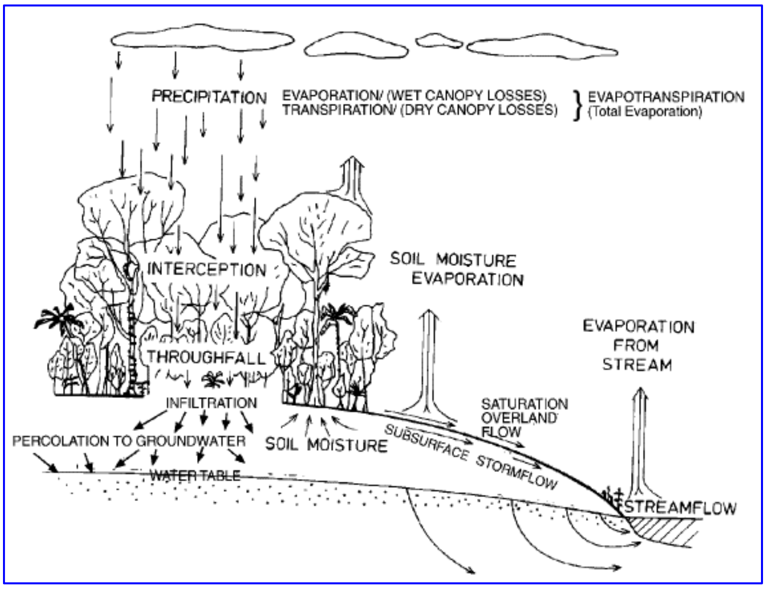


Figure 3: Tropical forest hydrology cycle (after Gilmour, 1975)

The area of land covered by forests is important to hydrological cycle. By intercepting rainfall, evaporating moisture from vegetative surfaces, transpiring soil moisture, capturing fog water and maintaining soil infiltration, a forest influences the amount of water available from groundwater, surface watercourses and water bodies (FAO, 2005b). The timing of water delivery is influenced by maintenance or improvement of soil infiltration and soil water storage capacity (Figure 4).

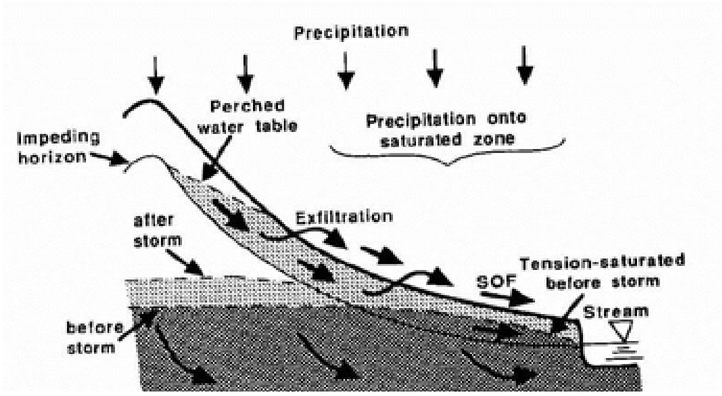


Figure 4: Diagram of the thickness of saturated layer thickens downslope until it equals the capacity of the soil to transmit water (FAO, 2005b)

Rainfall-runoff relationship is influenced by catchments' features i.e. land use, topography, soil type and area, as well as river network and its physiology. In a forested area, the rainfall is intercepted on the leaves of trees, and it reaches the ground as through fall and flows on the tree stems as stemflow. The flow then infiltrates into the soil and flows to the lower level to streams as surface runoff. Time concentration, which is the time taken by rainfall to flow as surface runoff is longer in forest area. In other land use area where soil permeability is low, surface runoff is higher and the time concentration is lower. With fewer trees in open areas, most of rain water reaches the ground as surface runoff and this might cause flood in case of high intensity and long duration of rain events (UPM, 2017).

Climatic factors are closely related to rainfall variability, temperature reduction or increment and frequency of climatic cycles, and it is varied in tropics. Global climate changes impact all the natural as well as ecosystems in tropics (Bazzaz, 1998). These fluctuations in atmospheric temperature, sea surface temperature, rainfall or other parameters can be quasi-periodic, often occurring on inter-annual, multi-annual, decadal, multi decadal, century-wide, millennial or longer timescales (Yousef, L.A & Ouarda T.B.M.J, 2015). The warmest water, as is the greatest rainfall, is found in the western Pacific. Winds near the ocean surface travel from east to west across the Pacific (these winds are called easterlies).

4.2 Tropical Rainforests

Tropical rainforests are very wet places, receiving heavy rainfall either seasonally or throughout the year. The area is close to the equator and gets lots of sunlight and warmth with uniformly high temperatures - between 20 and 35°C. The average annual rainfall is normally more than 200 cm rainfall per year.

Forest area, consisting of vegetation, flora and fauna, depends on its source to live and able to support local ecosystem with its ecological function by providing clean air and water. Forest area is not only valuable natural resources that plays a very important role in our ecosystem but also has its own ecstatic values.

According to FAO (2000), forest can be defined as: *Land with tree crown cover (or equivalent stocking level) of more than 10 percent an area of more than 0.5 hectares (ha). The trees should be able to reach a minimum height of 5 meters (m) at maturity in situ, may consist either of closed forest formations where trees and undergrowth cover a high proportion of the ground; or open* *forest formations with a continuous vegetation cover in which tree crown cover exceeds 10 percent. Young natural stands and all plantations established for forestry purposes which have yet to reach a crown density of 10 percent or tree height of 5 m are included under forest, as are areas normally forming part of the forest area which are temporarily unstocked as a result of human intervention or natural causes but which are expected to revert to forest. Includes: forest nurseries and seed orchards that constitute an integral part of the forest; forest roads, cleared tracts, firebreaks and other small open areas; forest in national parks, nature reserves and other protected areas such as those of specific scientific, historical, cultural or spiritual interest; windbreaks and shelterbelts of trees with an area of more than 0.5 ha and width of more than 20 m; plantations primarily used for forestry purposes, including rubberwood plantations and cork oak stands but excluded land predominantly used for agricultural practices.*

Tropical rain forests have large trees that are green year-round due to the consistent levels of rain they receive. This evergreen forest is abundant, inspiring, and a constant source of new scientific discoveries. Most tropical rain forests lie close to the equator which is between 10˚N and S (Elias, P & May-Tobin, C., 2011).

There are three major regions of rain forests, separated by oceans: Southeast Asia, Central Africa, and Amazonia, each with different species and structure. The tropical rain forest biome covers about 17 million km^2, or about 12% of Earth's ice-free land surface (not including extreme areas like Antarctica) (Figure 5). Of this area, approximately 20% was used as pasture or cropland in 2000 (Ramankutty et al., 2008). This estimate does not include land that had been previously converted but subsequently abandoned. However, while human use has affected more than 20%, there are still vast areas of undisturbed rain forests.

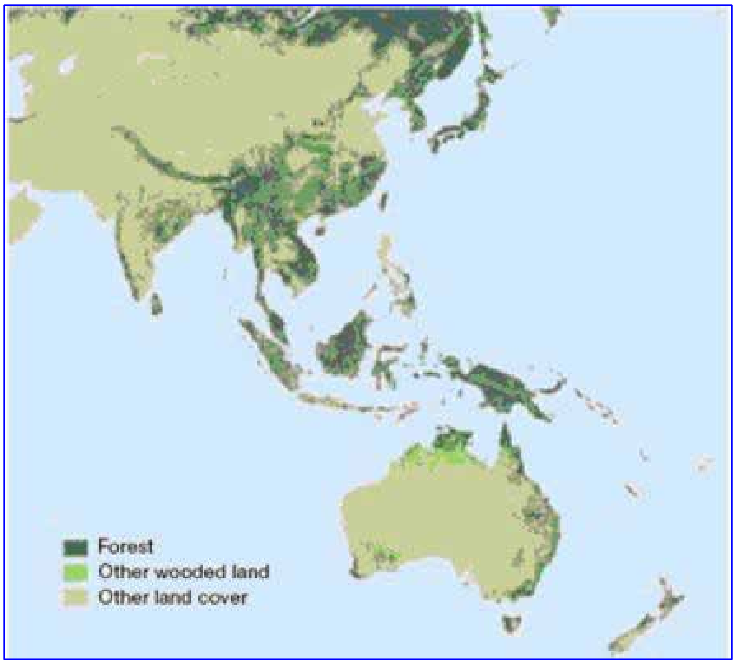


Figure 5: Distribution of forests and other wooded land in Asia and the Pacific (after FAO, 2005b)

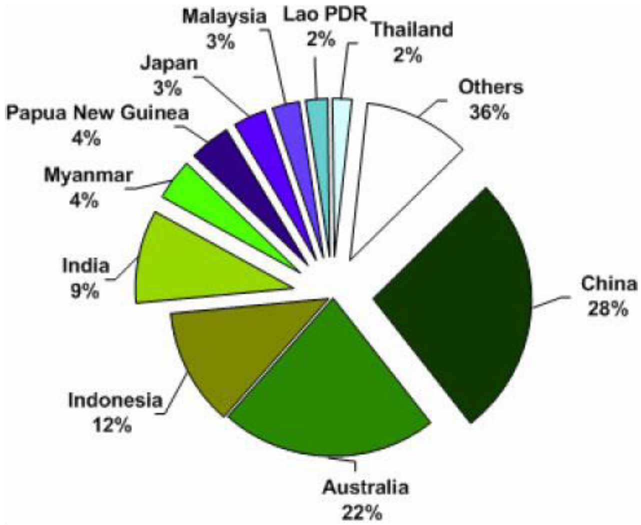


Figure 6: The ten countries with the largest forest area in Asia and the Pacific (after FAO, 2005b)

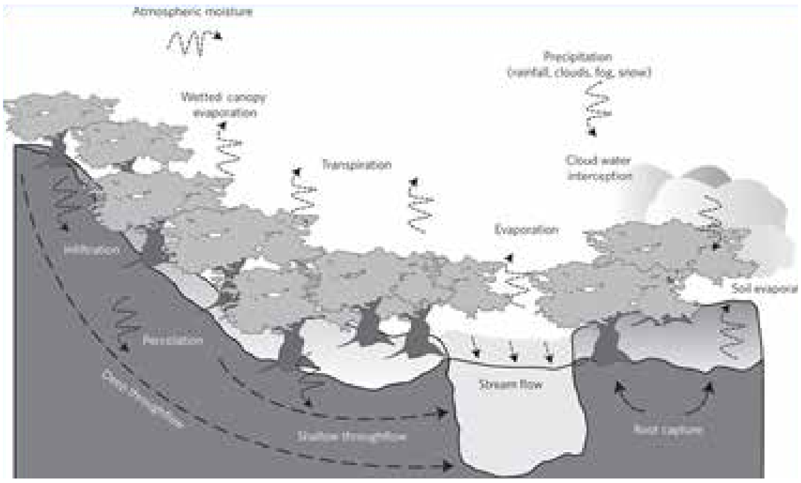


Figure 7: Hydrological function of forest (after Bruijnzeel et al., 1992)

The most important hydrological function of forest is to provide enough and clean water (Figures 7 and 8). Forest has the availability to absorb water during rain event, store it and then release it during dry period through its sponge effects (Bruijnzeel et al., 1992). Natural filtration and nutrient cycling in soil and forest vegetation is able to provide clean water to water bodies in forest areas. Among the function of canopy of vegetation are intercepting precipitation, changing rainfall drop size, reducing velocity of rainfall. The through fall that falls through tree canopy are able to alter rainfall chemistry and leave traces on leaf. The largest forest function is production, followed by multiple use including sources for community, protection of soil and water, conservation of biodiversity, recreation and education purposes (Figure 8).

The evapotranspiration (ET) is generally maximum in forest canopy due to high density of canopy and less opening in forest (Figure 8). However, the process depends on leaf structure, tree architecture and water use of different tree species in the forest area. Forest has these abilities through its characteristics which include canopy of the vegetation and rooting system of the vegetation, forest litters on the forest floors. Undisturbed forest consists of multi-strata forest cover compared to disturbed forest (Figure 9).

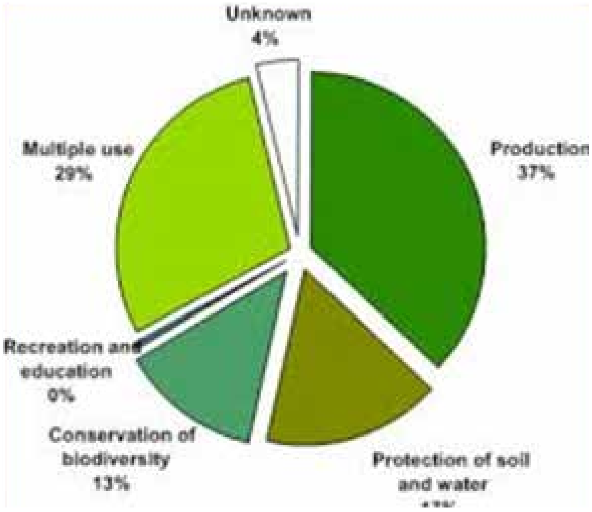


Figure 8: Forest functions (after FAO, 2005b)

Figure 9: Canopy opening for logging road construction during selective logging (after UPM, 2017)

The litters on forest floors depend on the depth and roughness of its surface. It greatly increases infiltration of precipitation, and the ability of the forest floors to hold water is highly variable. The forest floors especially on the riparian zones, as the litter slows overland flow velocity, traps sediment and sequester nutrients before the runoff enters the water bodies.

Another characteristic of a forest is the complex rooting system. The rooting networks which stabilize the aggregates and streambanks reduce erosion and sediment. The roots are also able to increase macropore space and preferential flow/infiltration. The deep rooting system takes up water and nutrients from deep in the soil profile (UPM, 2017).

The Selective Management System (SMS) allows flexible timber harvesting regimes based on pre-felling inventory data. The system limits the disturbance of forest catchment by reducing the allowed number of trees for harvesting (15 trees/ha), and tree size (60 cm at diameter breast height). It has become a dominant method of commercial logging in the tropical rainforests of Asia and the Pacific region. Selective logging has been widely applied in Malaysia since the 1980s, and is designed to minimize the impact of logging on soil, vegetation and water in the forest catchment. It allows subsequent logging in 30 years' time in the same forest area. It has been recognized that this method minimizes the impact on the forest (Yusop and Suki, 1994) compared to uncontrolled logging.

However, because of the limited number of trees harvested, and the slight effect on the growth of unharvested trees, recent reports have suggested that its damage is potentially serious and not worth the disturbances (Griesier, 1997). Selective logging operations involve road construction, canopy clearance, tree harvesting and skidding, and have increased the percentage of bare soil and impermeable areas within forested catchments.

4.3 Oil Palm Agriculture

The weather plays important role in palm oil production as insufficient water would disturb growth and oil palm fruit production. Loss of productivity by 20% has been reported during drought period in Malaysia from a severe El-Niño event.

Common types of agriculture crops in tropics such as oil palm, rubber, cocoa and tobacco, are often an important backbone for the local economy. Oil palm (Elaeis guineensis) is cultivated on approximately 15 million ha across the world (Fitzherber et al., 2008; Koh and Ghazoul, 2008; Koh and Wilcove 2008). Malaysia became the second largest producer after Indonesia accounting for 11% of world's oils and fats production and 27% of export trade of oils and fats (MPOB, 2013).

Roundtable on Sustainable Palm Oil (RSPO), an international organization of producers, has defined sustainable palm oil production as legal economically viable, environment friendly approaches and socially beneficial management and practices (Tan et al., 2009). RSPO has recently established as set of principle and criteria for the management of oil palm and palm oil mills and encouraged the planters to follow Best Management Practices (BMPs) (Lord and Clay; 2006). These practices are more environmental friendly by using approaches like zero burning for land clearing, conservation of wildlife and habitat, integrated pest management (IPM) and waste minimization and recycling.

In scientific community, there has been an issue regarding positive and negative aspects on the expanding of oil palm cultivation. Environmental risks have been discussed at length in scientific literature (Lamade and Boillet, 2005; Basiron, 2007; Nantha and Tisdell, 2009). The most contentious environmental issue in oil palm industry is deforestation as huge tracts of tropical rainforest are converted to plantations (Germer and Sauerborn, 2008). Peat Swamp forest has not been disturbed as this land is not suitable for agriculture process. However, increasing international demand on biofuel plus with lack of land and mineral soils has accelerated the conversion of peat land, into oil palm plantations (Sheil et al., 2009; Tan et al., 2009). Moreover, the drainage results in rapid peat subsidence and compaction were led to various changes in its physical properties. These were including greater bulk density and less total porosity, oxygen diffusion as capacity available water volume and water infiltration rate.

Oil palm is tolerant of a wide range of soil types, as long as it is well watered. Typically, oil palm trees are planted at a 9 m x 7.5 m spacing therefore a total of 148 palms/ha. In Malaysia, MPOB (2012) deliberates that there are two drainage systems for best management practices of oil palm cultivation on peat land (Figure 10). It is for mitigation measure to control peat subsidence by practicing optimal ground water-table management.

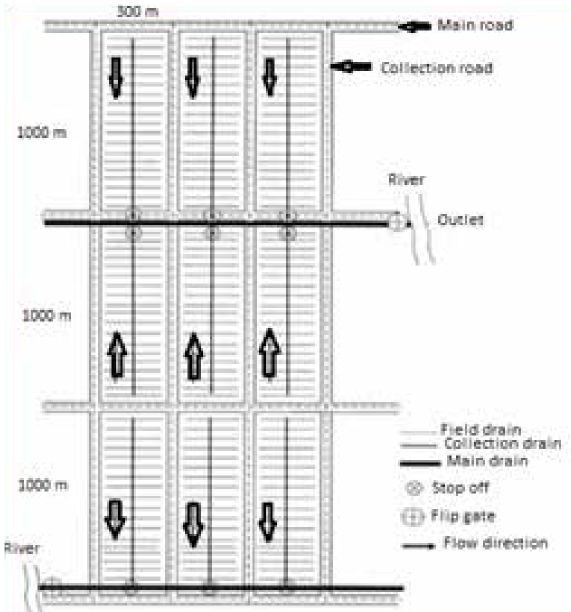


Figure 10: Typical example of controlled drainage system in a peatland (after Lim et al., 2012)

Conversion of forests involves removing natural forests to meet other land needs, such as plantations, agriculture, pasture for cattle settlements and mining. Among these land needs, agriculture is globally believed to be one of the main causes of deforestation. Around the world, forests are cleared (Figure 11) for plantations for oil palm, soy, rubber, coffee, tea, and rice among many other crops. Of increasing concern is the soaring popularity of biofuel. Biofuel is generated from oil extracted from plants such as oil palm – which are often grown on land cleared of natural forests.

When forests were converted to oil palm plantations, the sites were cleared of trees and shrubs for the purpose of agriculture. Some of the cleared vegetation and shrubs were left on the plantations to decompose which further serve as manure to the soils and help to improve the fertility of the soils. Some cleared vegetation was burnt before further cultivation was done in preparation for the new cultivation. The methods of site clearing became significant owing to the threats the indiscriminate site clearing like burning poses to the environment and water quality of the plantations in question. The burning method of site clearing poses threat to groundwater. According to Schlesinger (1997), soil and plant biomass, known to store terrestrial carbon, contain approx. 2.7 times more carbon than that stored in the atmosphere. Hence, the conversion of peat swamp forests to cropland like oil palm plantations releases CO_2 and other GHGs to the atmosphere as a result of fossil fuel burning and microbial decomposition of organic matter stored in the plant and soil biomass which further aggravates climate change.

Apart from the threats to the environment, water resources of the plantations have not been spared either. The clearing of the vegetative covers of the peatland exposes the soil to erosion, which further exposes the groundwater to the debris and other harmful substance from soil surface thereby polluting it. According to Tanga et al. (2005), conversion of agricultural forest, grass, and wetlands to urban areas usually comes with a vast increase in impervious surface, which can alter the natural hydrologic condition within a watershed. Consequently, the water quality is eroded and this becomes one of the risks involved in oil palm cultivation as a result of threats to freshwater streams which numbers of local communities depend on for drinking and their livelihood.

Figure 11: Logging for peat swamp forest conversion for agriculture (UPM, 2017)

In Malaysia, several numbers of policy makers and governmental agencies in the industry have recommended some tailored BMPs to correct some certain measures being practices in the plantation activities that are threatening the sustainability and efficiency of the oil palm industry. Among the recommended practice in the area of site clearing is zero burning policy. All the NGOs such as RSPO, GEC, NAP, and national and international agency like, MPOB, and Wetland International recommended the principle of zero burning as the major method of land clearing prior to oil palm cultivation. In other words, for oil palm sustainability on peatland, zero burning method for site clearing is encouraged. This is to avoid peat swamp degradation which affects their hydrological and ecological usefulness while improving on soil fertility.

Clearing of sites in preparation for cultivation of oil palms on peat soil is of great concerns to oil palm managers. As shown in Figure 12, is commonly referred to as zero burning policy and has been globally encouraged as it poses no threat to both the soil and the environment.

Figure 12: Zero burning policy prior to oil palm cultivation (after UPM, 2017)

The oil palm managers have seen this method as the best option for its suitability in converting other crops like cocoa and coconut into palm cultivation.

Highlighted in the Appendix B are various management practices in the oil palm industry. For the optimum oil palm production, particularly on peatland, certain policies must be followed in order to produce the desired results that would favor both the industry in terms of yields and output and the environment.

5. Environmental Water Security in Asia and the Pacific Region

Water security continues to be one of the great challenges in Asia and the Pacific. Its impact on human well-being and development is immense and indisputable. Water-related disasters affect a greater number of people in Asia and the Pacific than in all the other regions combined. The cities in the region are growing, and the management of their water and sewerage systems is a matter of concern, as is the health of rivers and water bodies. Climate change and its accompanying uncertainties exacerbate the situation in many ways (ADB, 2016). Water security is more than just providing sufficient water for people and economic activities. It is also about having healthy aquatic ecosystems and protecting us against water- related disasters.

The environmental water security indicator assesses the health of rivers and measures progress on restoring rivers and ecosystems to health on a national and regional scale. The sustainability of development and improved lives depends on these natural resources. An important step forward is to encourage river health monitoring at the country and basin levels, together with strengthening coordination and cooperation among individual infrastructure projects.

5.1 Environmental Water Security

Linkages to SDG 6:

- By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes.
- By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally.

How well river basins are being managed to sustain ecosystem services can be accessed through statistical information, index, modeling from:

- River health.
- Flow alteration.
- Environmental governance.

The index of environmental water security used by Asian Development Bank (ADB) quantifies the pressures on the health of flowing surface waters across the region. It includes (i) the river health index (RHI), which is the inverse of a metric of threat to water security, that incorporates the potential impacts of many variables that tend to have detrimental impacts on river health; (ii) flow alteration, which describes the extent to which rivers are changed due to dams, weirs, and direct extractions; and (iii) environmental governance, which expresses the efforts of governments to protect the environment in their country (ADB, 2016).

According to the study by ADB (2016) the results for environmental water security show that some countries score fairly high while others score quite poorly (see results by sub-region in Figure 13). Countries that show relatively high scores for environmental water security span almost the complete range of economic development. Countries very early on their path toward development, such as Papua New Guinea, have high scores, primarily as a result of higher values for the RHI and limited alteration of river flows. Other countries, such as Australia and Singapore, scored quite high for the entire index because of a strong governance regime that provides the capacity to mitigate existing pressures on the environment. Detailed results for the countries in the region can be obtained from Appendix 5 in the ADB (2016).

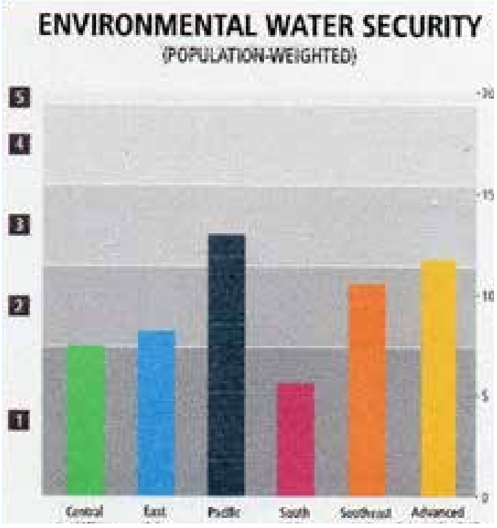


Figure 13: Environmental Water Security in Asia and the Pacific Region (after ADB, 2016)

Note: The units on the right axis are the scores (1–20 scale); the ones on the left axis are the stages (1–5 scale from hazardous to model).

5.2 River Health Monitoring

5.2.1 River Auditing

Rivers are our source of life and by understanding the issues, public and community can play their role in protecting rivers and its environment such as involved in "let us get to know our rivers" through programme such as carrying out river auditing. Government agency can, with the help of and working together with NGOs, prepare a small booklet and river health check form. The booklet may contain information such as who owns our rivers? what is a river?, brief description of rivers in the country, what is a river basin?, why are rivers so special?, natural rivers (living entities, meanders, riffles and pools), classification of rivers (the designated used of water, water quality classification), status of rivers in the country, source of pollution in rivers, effects and impacts or river pollution and information for river auditing such as ecology studies, water quality, hydrology, river mapping, polluter monitoring, map your river inlet and outlet (Figure 14), survey, design & safety, etc. Example "river health check form" by an NGO Global Environment Centre (GEC), Malaysia is shown in Appendix A.

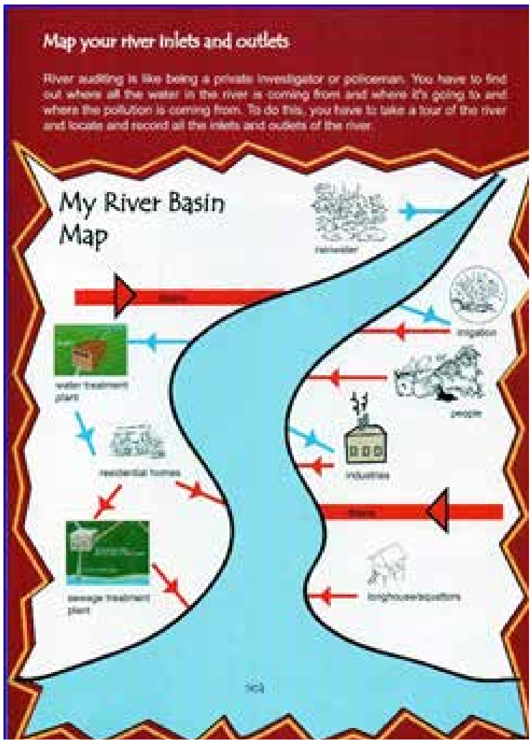


Figure 14: Mapping your river inlet and outlet (after GEC, Malaysia)

5.2.2 A River Keeper's Field Book

The relevant authority(s) in the Asia and the Pacific region countries can also monitor river health environmental water security by using what is known as 'a river keeper's field book' such as practice in Denmark. The river nature care field book can be used to carry out job to care for and maintain the watercourses.

The scope and detail of the book would be of use to the authority and at the same time be of value to others who take an interest in the watercourses. Good water flow should not be the sole objective, as environmental health conditions including the surroundings is of equal importance. The regulations for each watercourse must be laid down in a directive. The book should explain the various regulations governing the watercourses and the special requirements for goods, natural conditions. It also should describe some of the animals and plants that live in the watercourses and their immediate surroundings (Madsen, 1995). The book can be divided into several sections such as taken from Madsen (1995) :

- Introduction. The watercourses of the past and why they must be treated differently today. The content can include: quality of rivers and stream, changing the watercourses is nothing new, who are using the watercourses, etc.
- Animals and Plants. The plants, fish and other animals in the watercourses and their immediate surroundings. The content can include: fish in the watercourses, vertebrates, aquatic plants, invertebrates in the water, plants in the banks, invertebrates in the banks, what makes a good stream, large animals found near rivers and streams, etc.
- The Watercourse. The water and environmental conditions of rivers and stream. The content can include: the water (water in stream, water level and flow, when the weed should be cut?), the quality of the water (wastewater consume oxygen, oxygen in the water), the physical properties of the watercourses (the natural stream, riffles and pools), the banks of the watercourses (plants and trees on the banks), etc.
- Treatment. How to improve the watercourses and introduce good environmental conditions. The content can include: considerate maintenance, removal of waterweed, can include: the treatment of wastewater, the quality of the watercourses, administration of the watercourses, the watercourses act, agriculture, nature conservation act, freshwater fishing act, who has access to the watercourses, etc.

6. FAO on Forests for a Greener Future in Asia and the Pacific Region

With only 0.2 hectares of forest per person, the Asia and the Pacific region is, per capita, the least forested region in the world. Reinvestment in forests is necessary to reduce timber import dependence, support biodiversity conservation and climate change mitigation, revitalize rural economies and protect land and populations from environmental hazards and the impacts of climate change (FAO, 2011).

Since 1990, 38.7 million hectares of primary and other naturally regenerated forest have been lost in the Asia and the Pacific region, an area greater than the size of Japan. The overall low levels of per capita forest area in the region make these reductions even more significant. In South Asia, in particular, 23 percent of the world's population relies on only 2 percent of global forest resources and per capita forest area stands at only 0.05 hectares. The largest total reductions in forest area since 1990 were, however, in Southeast Asia where deforestation amounted to 33.2 million hectares or 7.6 percent of the land area (Figure 14) (FAO, 2011).

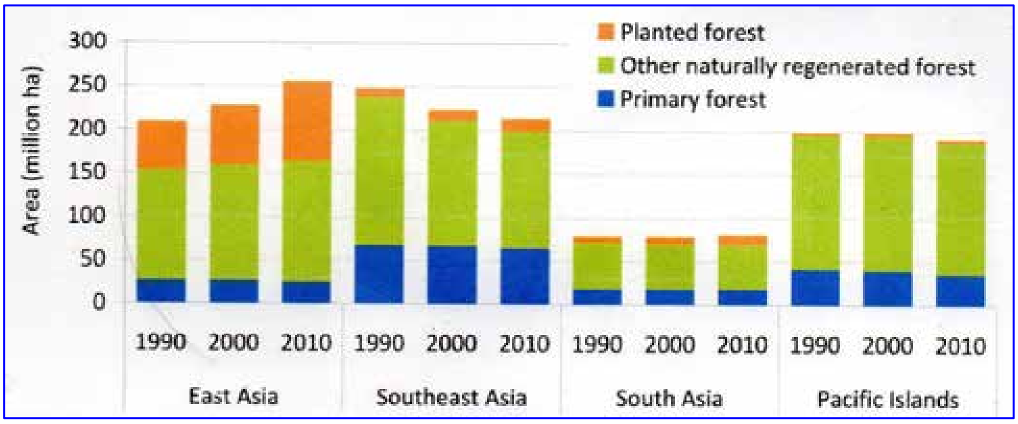


Figure 15: Forest area by category in Asia and the Pacific sub regions, 1990-2010 (after FAO, 2011)

Table 1 shows the agricultural area and forest area statistics.

Table 1: Agriculture and Forest Area Statistics in Asia and the Pacific Region (after FAO, 2011)

Country	Country Area (1000 ha)	Land Area (1000 ha)	Agricultural Area (1000 ha)	Forest Area (1000 ha)	% Forest Area over Land Area
Australia	774122	768230	406269	124443	**16.2**
Bangladesh	14763	13017	9099	1431.6	**11.0**
Brunei	577	527	14.4	380	**72.1**
Darussalam	18104	17652	5455	9584.4	**54.3**
Cambodia	328725.9	297319	179721	70503.6	**23.7**
India	191093.1	181157	57000	91694.4	**50.6**
Indonesia	37796.2	36456	4519	24959.6	**68.5**
Japan	23680	23080	2369	18572.24	**80.5**
Lao People's Democratic Republic	23680	23080	2369	18572.24	**80.5**
Malaysia	33032	32855	7839	22180.8	**67.5**
Mongolia	156412	155356	112936.5	12650.08	**8.1**
Myanmar	67659	65308	12645	29587.4	**45.3**
New Zealand	26771	26331	11116	10151.8	**38.6**
Pakistan	79610	77088	36252	1515	**2.1**
Papua New Guinea	46284	45286	1190	33561.8	**74.1**
Philippines	30000	29817	12440	7800	**26.2**
Republic of Korea	10028	9748	1748.3	6191.6	**63.5**
Singapore	71.9	70.9	0.66	16.35	**23.1**
Sri Lanka	6561	6271	2740	2076.6	**33.1**
Thailand	51312	51089	22110	16369	**32.0**
Timor-Leste	1487	1487	380	697.2	**46.9**
Viet Nam	33096.7	31007	10873.7	14644	**47.2**

7. Lessons Learnt and Remarks

- The loss of forested areas and altering the forest landscape have a direct impact on the hydrological cycle, and also leads to heavy erosion, eliminates the uptake of nutrients, and disturbs food and habitat for aquatic ecosystems. Therefore, it is imperative to understand the impact of human activities on forests to further improve land and watershed management such as forest cover in the watershed is the best cover for drinking-water supply watersheds, because most forestry activities involve no use of fertilizer, pesticide and fossil fuel or outfalls from domestic sewage or industrial process. The quality of rivers depends on the amount of pollutants entering the water bodies.
- In Asia and the Pacific, it is a major challenge to halt many factors contributing to forest degradation or deforestation in the future. There are many opportunities for controlling and minimizing its negative impacts such as include the protection and management of remaining forests, socio-economic development in rural areas and policy and institutional reforms.
- Maintaining a good riparian cover along a stream will help preserving stream ecosystem.
- The rooting networks of forest which stabilize the aggregates and streambanks reduce erosion and sediment.
- Selective logging designed through the Selective Management System (SMS) can minimize the impacts of logging on soil, vegetation and water in the forest catchment.
- Best Management Practices (BMP) are more environmental friendly by using approaches like zero burning for land clearing, conservation of wildlife and habitat, integrated pest management and waste minimization and recycling.
- Oil palm is tolerant of a wide range of soil types, as long as it is well watered.
- River health environmental water security monitoring should be encouraged at the country and basin levels, together with strengthening coordination and cooperation among individual infrastructure projects.
- Public and community can play their role in protecting rivers and its environment such as involved in “let us get to know our rivers” programme or carrying out river audits with assistance from NGOs and Government Body(s).
- The relevant authority(s) in a country could monitor river health environmental water security by producing and using what is known as ‘a river keeper’s field book’.

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Appendix A

Example of River Health Check Form (after GEC, Malaysia)

This form allows you to record your physical, chemical and biological observations of the site and its environment. It is important to keep good notes on each site, recording the location, date and details on anything special that might vary from visit to visit.

You can then compare different rivers or different sites along the same river. This is important so you can compare your scores if you visit the site over time.

Summarise your results and send us a simple report on the health of your river every 3 months.

address Global Environment Centre
2nd Floor, Wisma Hing, No. 78 Jalan SS2/72
47300 Petaling Jaya, Selangor D.E., Malaysia.
phone +603 7957 2007
fax +603 7957 7003
email kalithasan@genet.po.my

Site Description

Name of waterway / site :

Date :

Time :

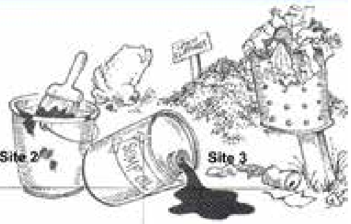
Weather :

Has it rained in the past 24 hours?
(if yes, was it heavy?)

Global Environment Centre

Name :
Contact details :
School / organisation :
Crew size :

physical monitoring



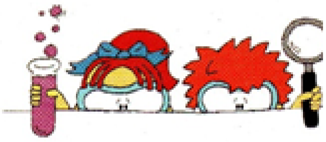
Please draw your local area map first (see back cover)

Now, look around you and describe what you see according to the different attributes.

Attribute	Site 1	Site 2	Site 3
Colour & Appearance			
Smell			
Vegetation			
Animals			
Activities *(land use, human activities, points of interest e.g. construction, industry, drain feeding river)*			

chemical monitoring

Record your results from the water quality tests here.



Variable	Site 1	Site 2	Site 3
pH			
DO			
Turbidity			
Phosphate			
Nitrate			
Temperature			
Ammonia			

biological monitoring

Identify the organisms you have found using the biomonitoring cards and list them down here.

	Species	Indicator	Water Quality
Site 1			
Site 2			
Site 3			

Appendix B

Policy framework for the Best Management Practices in Oil Palm Plantation (after UPM, 2017)

Policy Maker	Peatland Water Management	Fertilizers Management	Pest and Disease Management	Site Clearing Management	Peatland Biodiversity	References (URL)
	A. The depth of water level in the canals should be maintained so as to allow movements of vessels irrespective of the season (RSPO, 2012)	A. Due to the high porosity of peat which encourages fertilizer leaching, strict timing of fertilizers should be ensured (RSPO, 2012)	Though some pests are beneficial to peat formation on in breaking down the dead woods into organic matter, but due to the negative effects of pests attacks on oil palms, below are the policies being put in place to address the menace;	Zero burning method for land clearing prior to cultivation is encouraged. This is to ensure unnecessary degradation of peat swamp which consequently affects their hydrological and ecological functions.	Tropical peat swamp forests are forested wetland characterized by deep layers of peat soil and waters where high diversity of plant and animal species are found.	http://www.rspo.org/file/RSPO_BMP_1_Update_24_April_2013_small.pdf ; http://www.rspo.org/file/RSPO_BMP_1_Update_24_April_2013_small.pdf AND http://rt9.rspo.org/ pres/ pcfinals/pc3/ PC3.7_Dr_Arina_ Schrier.pdf
	B. The water table of the entire area should be maintained at 60-75 cm below the ground surface, as desired by the oil palm trees. [note Current best management practice is to maintain water levels at 50-70 cm] RSPO, 2012)	B. Fertilizers application should be avoided during the raining season as the rain aids the leaching of fertilizers into the ground surface (RSPO, 2012).	A. Monthly census on every oil palm and speedy treatment should be implemented.	This prohibition of site burning as a mean of site clearing for cultivation on peat swamp also reduces peat fires (RSPO, 2013).	These forests play major roles in preserving water supply, controlling and mitigating flood damage, providing fish, timber, and other resources for local communities, and regulating the release of greenhouse gases by storing large amounts of carbon	

	C. The water management system (water level control in the canals and water table control in the field) system should not cause saltwater intrusion into the area. Planting riparian vegetation which increases surface and channel roughness serves to reduce the surface water that enters the river and reduce the discharge within the river. This helps in alleviating the magnitude and intensity of flooding downstream (RSPO, 2012)	Fertilizer trials to determine site-specific fertilizer requirements for the peat types and environmental conditions must be carried out by plantation companies with large scale oil palms planting (RSPO, 2012).	The recommended chemical for termite control is fipronil (5.0 % a.i.) with its application varying based on the age of oil palm.	It is critical that comprehensive environmental impact assessments are conducted to ensure that the proposed land clearing method and replanting do not have significant adverse impact on the peat swamp ecosystem.	Peat swamp forests and river within and adjacent to oil palm plantations should be conserved, maintained and rehabilitated to avoid pollution from discharge from peatland that could endanger the aquatic life	
		Leaf analyses and a prescriptive range of fertilizer recommendations should be encouraged for larger plantations and smallholders respectively.	Palms > 1 year – 5.0 liter/palm and Palms < 1 year – 2.5 liter/palm	Open burning within peatland area should not be permitted (RSPO, 2013)		
National Action Plan for Peatland (NAP)	Water Table limit not stated unlike RSPO. Collecting information on peatland water management in the fire prone peat areas and developing fire prone risk maps and prevention plans. Enforcing prevention, monitoring of water table levels, and forecasting control measures to reduce the risk of peat fires.	Fertilizers are to be applied with proper schedule and should be applied with rainfall pattern in mind. In the event of heavy storms, the fertilizers may be washed off	Integrated Pest Management (IPM) which uses pest and environmental information to prevent unacceptable levels of damage is recommended.	Zero-burning strategies for all commercial agriculture on peat swamp forests should be enforced so as not to impair the hydrology of the peatlands.	Separate and designate the peatlands which are of national importance for conservation of biodiversity. Identify unique species of peatland biodiversity and strengthen protection and recovery measures	http://www.cbd.int/doc/world/my/my-nr-05-en.pdf, and http://www.nre.go v.my/ms- my/PustakaMedia/Penerbitan/National%20Action%20Plan%20for%20Peatlands.pdf

	Establish baseline data for peat hydrology in peat basins					
ASEAN Peatland Management Initiative (APMI)	Optimizing water management in the peatland (Referred to as reducing peatland drains) will reduce the peat fires and further reduce the rate of GHGs emission, especially CO_2 emission as result of oxidation and fires. Also Undertake regular monitoring of peatland areas, including peatland water quality and physico-chemical conditions.	Use of 'coated' nitrogen will help to reduce N_2O emissions. Also fertilizer practices that optimizes N-fertilizers and maximize organic fertilizer use will help in reducing GHG emissions and should thus be encouraged	The use of chemical products that control the outbreak of disease is recommended. The key to minimizing both the economic impact of pest and environmental impacts from excessive use of chemicals is regular surveillance and monitoring. This allows potential devastating outbreaks to be nipped in the bud before they become difficult to contain.	General land clearing, except fossil fuel burning should is recommended. The remains of the old palm could be left to decompose which help in carbon sequestration rather than burning which further degrades the peat.	Drought and peat fires should be avoided to avoid biodiversity loss	http://environment .asean.org/wp-content/uploads/2 014/04/ASEAN-APMS_2013_05- FINAL. pdf
Global Environmental Centre (GEC)	Water management on peatlands should be based on the best available knowledge and techniques and carried out according to international conventions and regional and national legislation and priorities. Maintaining water levels in the field drains at 50 cm is recommended for obtaining good yield and reducing GHG emissions.	Fertilizer management plans is recommended which uses pest and environmental information with correct pest control methods to prevent unacceptable levels of damage by the most cost-effective means and with minimum possible hazard to man, non-target organisms, and the environment.	Integrated Pest Management (IPM) uses pest and environmental information with correct pest control methods to prevent unacceptable levels of damage.	Emphasis is on zero burning on the peatland. Since burning exposes carbon in the peat soil to atmosphere due to peat oxidation and zero burning reduces the risk of peat fire.	The peat swamp forests support a host of globally threatened and restricted-ranged plants and animals and therefore deforesting them should be discouraged. Malaysia, 2010).	file:///C:/Users/Us er/Desktop/2014_ enhancingforestry practices.pdf AND

Malaysian Palm Oil Board, MPOB	Groundwater level of 50-70 cm depth from the peat surface should be maintained for the best performance of oil palms planted in Peninsular Malaysia. For Oil palm of 1-3 years, 30-40 cm water level from peat surface; For oil palms of age 4-7 years (Young mature oil palms), 35-45 cm water level from peat surface; for oil palms of > 8 years (Fully Mature), 40-50 cm water level from peat surface required.	Precision agriculture should be practiced to enhance the exact fertilizer needs of the peat so as to prevent leaching in the course of high precipitation	Planters should ensure necessary control measures treatment such as periodical pests survey or efficient agricultural practices. Prevention programme that will prevent re- occurring of pest and disease attack is very important.	Burning should not be used as land clearing method as it releases the soil carbon to atmosphere	Drought and Peat fires should be avoided by maintaining a good water level of 40-50 cm in peatland drainage.	http://palmoilis.mpo ov.my/publications/ T/ TT-472.pdf AND http:// palmoilis.mpo ov.my/ publications/ T/TT-307. pdf AND http://www. epd2.sa gov.my/report_ epds nal_Report_Vol_III ategies_&_Action_ s.pdf
Wetland International	A good water management system for oil palm effectively maintains a water-level of 50-70 cm (below the bank in collection drains) or 20-30 cm (groundwater piezometer reading)	Since storm events increase the leaching of fertilizers to the groundwater body, strict timing and schedule for fertilizers is encouraged. There should be no fertilizations during the period of high storms.	Integrated Peat Management, IPM, should be practiced which involves good understanding of pest biology and ecology. This is needed in making the correct choice of physical, cultural, chemical and biological control methods. It is important to look for weaknesses in pest life cycles for targeting control.	Implementation of Zero Burning concepts that greatly reduce the risk of fires occurring should be employed.	Drainage should be maintained at a particular depth (40 cm below ground surface) to avoid drought which can cause peat fire and associated biodiversity loss	file:///C:/Users/Us er/Desktop/Wetla nds_Report_Peat_ Status_Malaysia.p df AND file:///C:/Users/Us er/Desktop/Assess ment1%20rev1.pd f

Food and Agriculture Organization of United Nations, FAO.	Where the water level is getting low as a result of drainage network system, the blocking of canals or ditches using dams and weirs made with different materials is done to raise water levels (FAO 2004)		Organic agriculture with unique production management system that promotes biodiversity and soil biological activity should be encouraged (FAO, 2001)		Implementation of fire management, rehabilitation of degraded forests, reducing forest fragmentation and elimination of additional stresses to forests, will make forests more resilient to fire biodiversity (FAO, 2003).	http://www.fao.or g/3/a-i4029e.pdf; http://www.fao.or g/ docrep/018/i332 4e/i3324e.pdf; http://www.fao.or g/ docrep/019/i367 1e/i3671e.pdf

About the Author

Dr. Mohamed Roseli has served in the Public Sector, working in three different government departments for 35 years and 10 months. He had served in the Department of Irrigation and Drainage (DID) Malaysia in the field of water sector since December, 1979 and has a wide experience in water resources management, irrigation, drainage (agriculture, urban and sub-urban), river ecosystem management, stormwater control at source management, flood alleviation management, ecohydrology and related engineering works.

As a former Director of HTC Kuala Lumpur (HTCKL) a category II UNESCO Water Centre for Hydrology and Water Resources, he has been involved in various projects and research related to water resources management, engagement with UNESCO counterpart and universities in the region (Southeast Asia and the Pacific) at national and local levels. He has implemented the Integrated Stormwater Management Ecohydrology (ISME) project at HTCKL. He is also actively involved in several Science, Technology and Innovation projects and programmes such as Development of Decision Support System (DSS) Design Kit for Stormwater Management Ecohydrology, Study on Performance of Gross Pollutant Trapping Device vs Life Cycle Cost and Gross Pollutant Management Strategies Knowledge Portal, River Rejuvenation for Social and Water Ecosystem Project, Point Source Waste Water Management, Application of A Stepped Solar Still System for Domestic Water Desalination and River Water Quality Improvement, Artificial Bio-Macropore for Stormwater Management, and A Novel Approach to Reuse Alum Sludge in Manufacturing of Building Material using Admixtures and Thermal Curing.

He has received a number of awards such as Gold Medal Award during 32nd International Exhibition of Inventions, New Techniques and Products of Geneva, Switzerland in 2004, Bronze Medal Award during the 34th International Exhibition of Inventions, New Techniques and Products of Geneva, Switzerland in 2006, Public Service Innovation Award in 2007, and Gold medal for R & D innovation product on Modular Floating Rubbish Trapper as well as Silver and Bronze medal for R & D Innovation Products during Science and Technology Competition in Malaysia.

Currently, he also venture in business marketing products related and not related to water. He continues to study on his own, topics related to water management.