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Holistic Approach to Water Resources Development through Generations

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ABSTRACT

Sustainable development of water resources systems must balance between socio-economic development and environmental protection. This is both a technical and governance challenge to reconcile the technical challenge of competing ecological-social-economic objectives and the governance challenge of harmonizing long-term policy frames and short-term management decisions. With climate and ecosystem changes and uncertainty as well as socio-economic and political changes, water resources development has become complex. In view of this, sustainable water resources development requires transdisciplinary approach that combines science-based tools from physical, social, economic, and behavioral sciences and engages stakeholders from various sectors (academics, professionals, government, civil society) to solve problems through an iterative process of collaborative learning, research, and consensus building. This paper discusses holistic approach for sustainable and resilient water resources development in the context of the following items: (1) linking science, policy, and management decisions through decision support systems; (2) sustainability science; (3) transdisciplinary approach; and (4) evolutionary resilience. Then, specific studies and discussions are given showcasing holistic approach for the following water resources systems: 1) Pasig-Marikina River Basin, 2) West Mangahan Lakeshore Road Dike, 3) Marikina River Flood Tunnel to Agos River, 4) New Centennial Water Supply Project for Metro Manila, 5) Pulangi Hydropower Plant IV Reservoir sediment flushing, and 6) Banaue Rice Terraces as an archetype of sustainable design. In conclusion, with climate and ecosystem changes and uncertainty including economic, social, and political changes, sustainable water resources development requires transdisciplinary approach with sustainability science and evolutionary resilience.

Keywords:
sustainable water resources development, transdisciplinary approach, sustainability science

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INTRODUCTION

The sustainable utilization and development of water resources systems must balance: (1) socio-economic development to satisfy basic needs, alleviate poverty, enhance economic and social equity, and improve the quality of human life; and (2) environmental protection to ensure ecological integrity of the environment and maintain biodiversity, biological productivity, and ecological resilience.

In view of this, sustainable water resources planning and management is both a technical and governance challenge. There is the need to reconcile the competing ecological-social-economic objectives (technical challenge) of the various actors (government, stakeholders, professionals, academics) with long-term perspectives and policy frames into short-term actions and management decisions (governance challenge).

The Brundtland Commission defines sustainable development as the kind of development that meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED 1987). Thus, the planning horizon for sustainable water resources development should be conducted in the context of sustainable development. Ideally, these studies should cover periods of 100 to 150 years (planning horizon) encompassing two to three generations. In this case, future scenario setting as far as land use plans, economic developments, and demographic change including climate change will be important to such planning studies.

In relation to sustainable water resources development, this is a complex problem and definitely non-deterministic, dynamic, and uncertain (also called wicked problem) due to ecosystem, land use, and climate changes and uncertainty including economic, social, and political changes. Thus, understanding and planning for sustainable water resources development encompasses spatio-temporal variations of physical, economic, social, and political factors and must cover infrastructural, institutional, economic, and social resilience, in the context of evolutionary resilience.

In view of this, sustainable water resources development can no longer be based on traditional science but rather based on sustainability science (Komiyama and Takeuchi 2011) and transdisciplinary approach is required which utilizes scientific tools (physical, social, economic, behavioral sciences) and engages stakeholders (academics, professionals, government, civil society) to solve problems through an iterative process of collaborative learning, research, and consensus building.

This paper discusses holistic approach to sustainable water resources development in the context of: 1) sustainability science, 2) transdisciplinary approach, and 3) on building resilience. This is followed by examples related to holistic approach to sustainable water resources planning and management for the following systems: 1) Pasig-Marikina River Basin, 2) West Mangahan Lakeshore Road Dike, 3) Marikina River Flood Tunnel to Agos River, 4) New Centennial Water Supply Project for Metro Manila, 5) Pulangi Hydropower Plant IV Reservoir sediment flushing, and 6)

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Banaue Rice Terraces as an archetype of sustainable engineering design. The paper ends with brief concluding remarks.

SUSTAINABILITY SCIENCE AND TRANSDISCIPLINARY

The concept of transdisciplinary was the inspiration behind the birth of sustainability science, proclaimed as a new academic held during the World Congress on Challenges of a Changing Earth 2001 in Amsterdam. Sustainability science differs from standard science in that it seeks a complimentary truth to traditional form of knowledge generation. It asserts that the search for sustainable solutions to global problems requires new methodologies that bring together the three pillars of sustainability: environment, society, and economy. This type of science is therefore envisioned to be a transformational scientific field with its transdisciplinary, community-based, interactive, and participatory approaches to education and research.

Table 1 shows how sustainable water resources development can be put in the context of sustainability science in contrast to traditional science according to five elements as adapted from Yoshikawa (2011): (1) aim of study, (2) mode of change, (3) truth verification, (4) result of research, and (5) expected outcomes.

Table 1. Sustainable water resources development in the context of sustainability science (SS) vs traditional science (TS).

Elements	Traditional Science (TS)	Sustainability Science (SS)	Difference TS vs SS	Sustainable Water Resources Development with SS
Aim of Study	To understand everything and manage individuals	To understand everything and manage their relations	Separate Disciplines vs Transdisciplinary	Understand and manage together ecological, economic and social including institutional components (i.e., avoid whole system to suffer by improving only part of it)
Mode of Change	Unchangeable (deduced from existence)	Slow change	Stable vs Unstable	Water resources systems changes with climate, land use, social, political and economic changes at micro/macro levels
Truth Verification	Experiments in laboratory	Evolution in reality	Certain (historicist) vs Uncertain (evolutionary)	Include computer simulations (4d lens) over so many years to account for uncertainties and dynamic changes
Result of Research	Knowledge for understanding	Knowledge for action	Analysis vs Synthesis	Sustainable water resources development with adaptive and resilience planning is iterative, inclusive and integrative to reduce the uncertainty and acknowledges the complexity of water resource system dynamics
Expected Outcome	Prosperity of human beings	Sustainability of the earth	Prosperity vs Sustainability	Not a single outcome but series of outcomes and actions building upon each other, enhanced and progressed over time as people and institutions learn from past experiences and decisions. Essence of evolutionary resilience.

(Note: First 4 columns of table above were adapted from Yoshikawa 2011).

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TRANSDISCIPLINARY APPROACH FOR SUSTAINABLE WATER RESOURCES DEVELOPMENT

Sustainable water resources development is a complex process due to the interaction, dynamics, and uncertainties of the three systems, namely: (1) ecological system due to global and local climate extremes and variabilities, changes in physical configuration and dimensions, etc.; (2) economical system due to varying economic objectives, benefit/cost, and externalities as well as investments and financing; and (3) socio-political system due to different societal objectives, social norms, and traditions, political ambitions, and culture of disaster.

Thus, sustainable water resources development encompasses the various disciplines from physical sciences, socio-economics, political science, to social, cultural, and behavioral sciences. According to van Kerkhoff (2013), transdisciplinary approach "transcends disciplinary pre-conceptions, but is capable of understanding and synthesizing across a range of disciplinary and non-disciplinary ideas and theories".

The main features of transdisciplinary approach are as follows: (1) it requires stakeholder engagement and collaboration involving academics, professionals, government units, non-government organizations, communities, and individuals (2) it is an iterative process of project development in consultation with stakeholders (3) to work collectively from problem identification, then knowledge generation to development of sustainable solutions and final project implementation; and (4) that decisions are made on hierarchical basis of (i) satisfying physical laws and constraints, (ii) sustainable ecological solution, (iii) sound economic basis, (iv) socially justifiable, and (v) politically acceptable solutions.

As shown in Table 2, transdisciplinary approach can be contrasted to monodisciplinary (isolated approach by individual experts), multidisciplinary (additive approach bringing together a wide range of experts), and interdisciplinary (interactive approach of several experts solving a problem together).

Table 2. Distinction of monodisciplinary, multidisciplinary, interdisciplinary and transdisciplinary approaches.

Monodisciplinary	**Multidisciplinary**	**Interdisciplinary**	**Transdisciplinary**
• isolated approach by individual experts • reactive	• proactive • additive approach bringing together a wide range of experts	• integrative • experts and stakeholders solve a problem by parts then integrate	• interactive and holistic • experts and stakeholders solve problem as a whole through interaction of parts

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Brown (2015) has interestingly elucidated in Figure 1 how stakeholders' transdisciplinary and role in participatory process comes naturally because of having a collective mind as an individual and as a community. In essence, the value of the several individuals in a community is that the collective mind is a collection of several cognitive functions based on individual experiences, physical observations, social narratives, ethical principles, aesthetic patterns, sympathetic feelings, and reflective synthesis.

ON BUILDING RESILIENCE FOR SUSTAINABLE WATER RESOURCES DEVELOPMENT

The importance of building resilience for sustainable water resources management cannot be overemphasized especially in relation to water-related disaster risk management. Three types of resilience can be defined as follows (Tabios 2020; Davoudi 2013):

- Engineering resilience is the ability of a system to resist and return to an equilibrium or steady-state after a disturbance such as natural disaster or a social upheaval so the faster the system bounces back to a single, stable equilibrium, the more resilient it is.
- Ecological resilience is the ability to absorb and persist before the system changes its structure and adapt to disturbance recognizing the existence of multiple equilibria and possibility that the system flips to an alternative stability domain.
- Evolutionary resilience is the ability of an ecological-socio-economic system to change, adapt, and crucially transform in response to perturbations, stresses, and strains and that a system is not conceived to return to normality. It acknowledges that systems are complex, nonlinear, and self-organizing permeated by uncertainty and discontinuities.

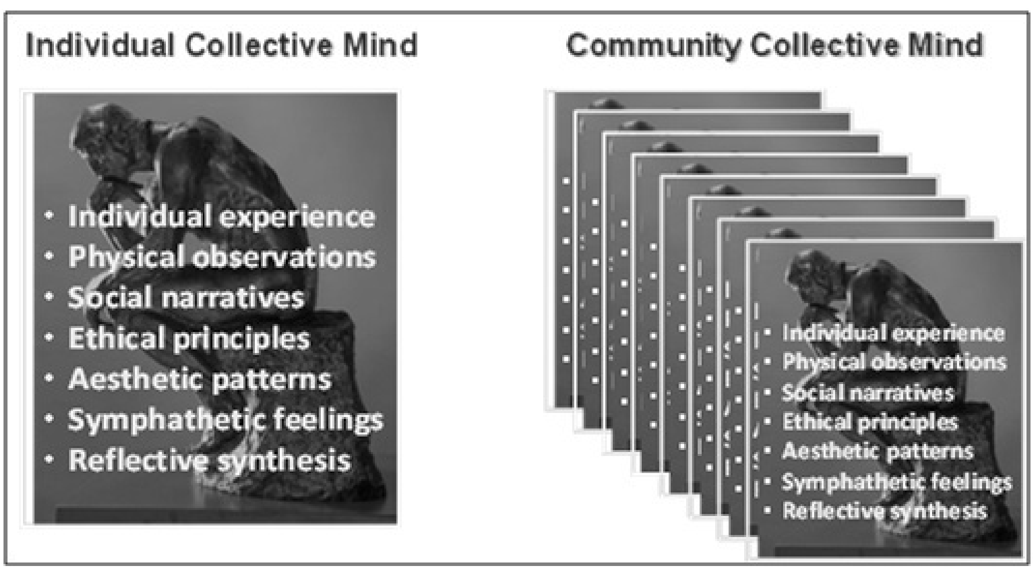

Figure 1. Cognitive functions of an individual and community collective mind (Brown 2015).

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In view of the complex dynamics and uncertainties of water resources systems and associated social, economic, and political dimensions, it appears that the most appropriate approach for building resilience to water-related disasters is evolutionary resilience and this logically fits into sustainability science for sustainable water resources development as discussed in Tabios (2020).

Sustainability science, transdisciplinary approach, and evolutionary resilience constitute the major elements of building resilience. Brown et al. (2012) discussed that resilience planning should bring together technical, scientific, and local knowledge into decision making processes by engaging multiple stakeholders using an adaptive cycle of action and reflection progressively learning as you do it and doing as you learn. It involves visioning and scenario planning considering future urbanization, land use, and hydro-meteorologic uncertainty. Resilience planning builds on iterative, inclusive, and integrated processes to reduce the uncertainty and complexity of rapid urban growth and changes in land use, socio-economics, and climate.

EXAMPLES OF HOLISTIC APPROACH FOR SUSTAINABLE WATER RESOURCES DEVELOPMENT AND MANAGEMENT

Holistic Flood Management of Pasig-Marikina River System

Flood risk management in an urban setting like Metro Manila is a complex problem which is an interaction of a dynamic and uncertain physical system, social system, and human system as shown in Figure 2 (Tabios 2010). This is owing to the

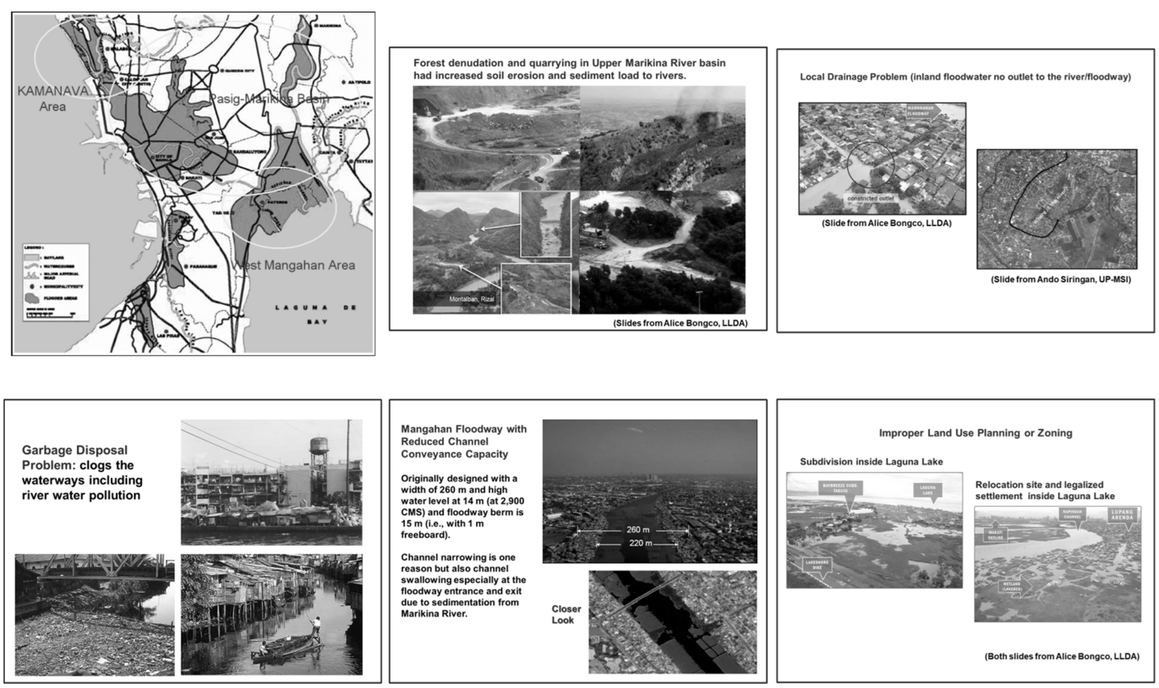

Figure 2. Urban dimensions of flooding issues in Metro Manila displayed (clockwise) (i) flood prone areas; (ii) forest denudation and quarrying in Upper Marikina River Basin; (iii) local drainage problem; (iv) garbage disposal problem; (v) reduced capacity of Mangahan Floodway; and (vi) improper land use zoning. (Tabios 2010) (West Mangahan Road Dike Project).

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various factors affecting floodings in Metro Manila from meteorological (typhoons, monsoons), hydrological (sedimentation, river changes, inadequate infrastructure), and human (garbage disposal, illegal settlement in rivers, river encroachment). Consequently, holistic flood risk management must encompass the various disciplines from physical sciences, socio-economics, political science as well as cultural and behavioral sciences. Thus, for sustainable flood risk management, a holistic approach is needed that integrates land, water, coastal, and hazard management as well as socio-economic and human dimensions in an urban setting. This is essentially in the framework of transdisciplinary approach and sustainability science (Tabios 2020).

Metro Manila floodwaters from Marikina River, instead of going straight to Pasig River, are diverted to Laguna Lake through the Mangahan Floodway for temporary storage. However, flooding occurrences along the north lakeshore towns of Taguig and Taytay became more frequent since the construction of the Mangahan floodway in 1982. In view of this, the government proposed the construction of a road-dike system to protect these towns from floodings. However, the project was opposed by various stakeholders that include fishermen, farmers, businesses, and lakeshore residents on the proposed lakeshore dike configuration (including alignment).

Through transdisciplinary approach, eight stakeholder consultations were held that resulted in six alternative lakeshore dike configurations that were subjected to an iterative process of review and value engineering. Figure 3 shows the alternative lakeshore dike configurations from stakeholder consultations that balance

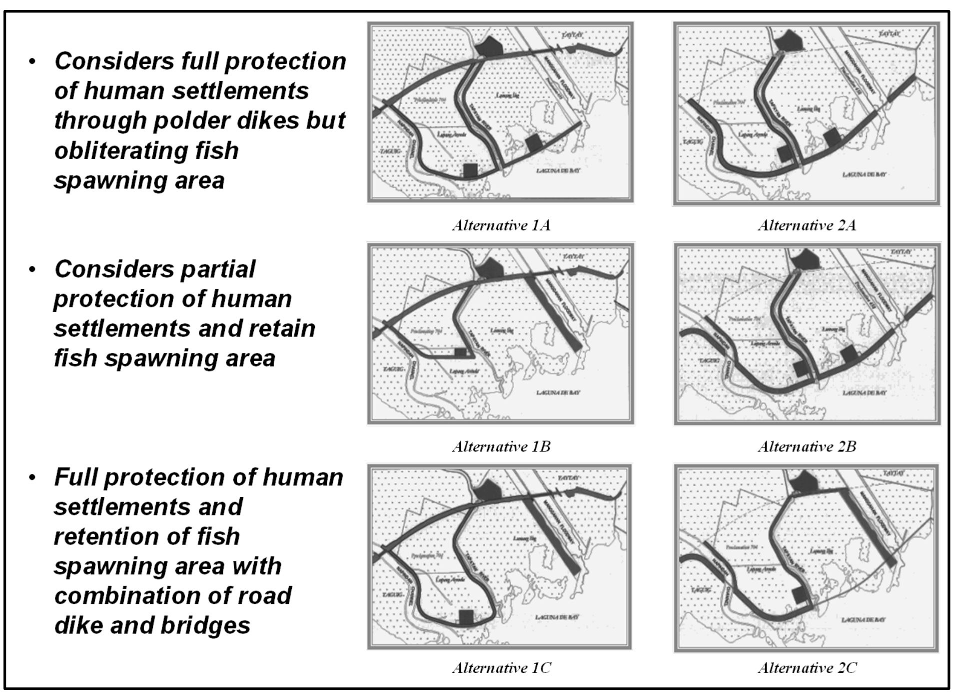

Figure 3. Alternative lakeshore dike configurations and alignment of the West Mangahan road dike project from a series of stakeholder consultations (Marikina River Stormwater Tunnel to Agos River Basin or Pacific Ocean).

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between full protection of human settlements or retention of fish spawning area.

Based on flood inundation levels, environmental impact, and economic internal rate of return, Alternative 1B in Figure 3 was selected which considers partial protection of human settlements and retention of fish spawning area.

As mentioned earlier, the flood control scheme of Marikina-Pasig River is to divert the floodwaters of Marikina River Basin through the Mangahan Floodway for temporarily storage in Laguna Lake. This is to alleviate flooding along Pasig River but the flooding problem was transferred to the lakeshore towns of Laguna Lake. A noteworthy solution is to divert 30-40% of Marikina River flows to Pacific Ocean through an underground flood diversion tunnel that traverses the Marikina River through Sierra Madre Mountain Range into the Agos River as shown in Figure 4. Also shown in Figure 4 is the flood hydrograph of Marikina River at Sto. Nino (with peak flow at 5,400 m3/s) as well as the resulting flood hydrograph at the same location (with peak flow at 3,600 m3/s) with a flood diversion tunnel to Agos River. In essence, by diverting the floodwaters to the Pacific Ocean, the flood control problem and associated investments due to river flooding along Pasig-Markina River will be drastically reduced.

New Centennial Water Supply Project for Metro Manila

In 1972, Laiban Dam in the Kaliwa River was identified as an alternative water source of Metro Manila. In the early 1980s, Laiban Dam project started, then stopped in 1986, due to change in administration, when in fact, about 20% of civil works were already completed. Attempts to revive the project were made during the terms of Presidents Ramos, Estrada, and Macapagal. However, there were various obstacles,

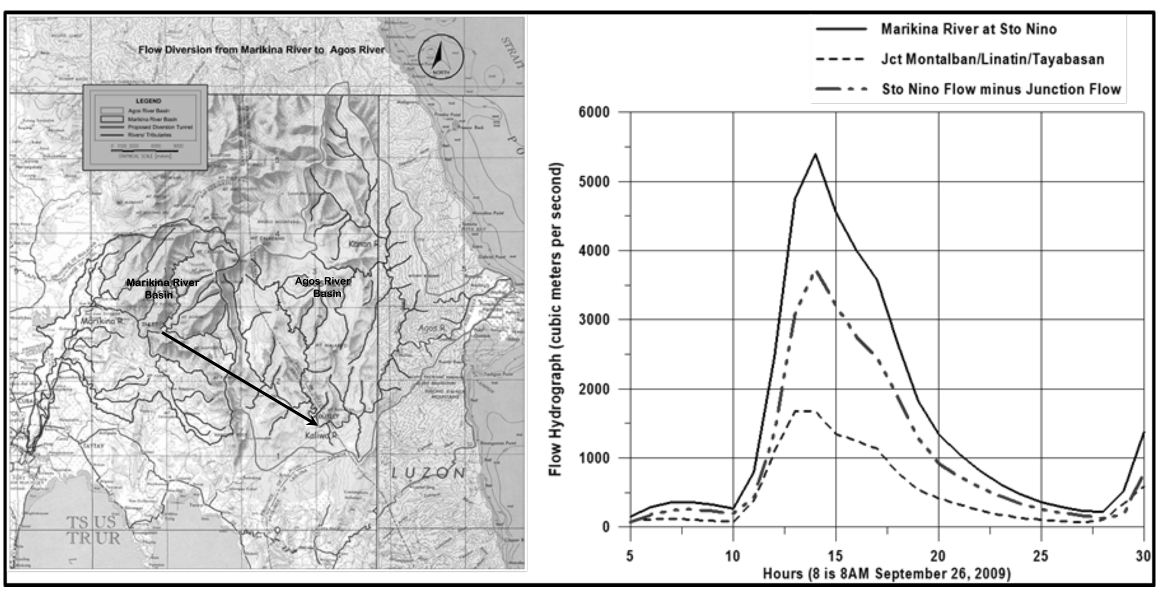

Figure 4. Alternative lakeshore dike configurations and alignment of the West Mangahan road dike project from a series of stakeholder consultations.

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especially funding and resettlement issues then. In 2012, President Aquino revived the project since Metro Manila's water supply had become critical due to increasing water demand. Also, aside from future water security, this project aims to provide redundancy, since Metro Manila cannot simply rely on Angat Reservoir as sole source of 85% of Metro Manila's water use. This was called the New Centennial water supply project for Metro Manila and the study for this was extended to cover the entire Agos River Basin with major tributaries, the Kaliwa and Kanan River that converges into Agos River.

For this purpose, a long-term reliability analysis using optimization-simulation with project sequencing and staging study was conducted for various river/reservoir/dam configurations in the Agos River Basin as shown in Fig. 5 such as with Kaliwa Low Dam alone, combination of Kaliwa and Laiban Dams, combination of Kaliwa and Laiban Dams with Kanan Diversion, among others. There were studies conducted in the Agos River but on monthly basis which may not be adequate for reliability analysis of a water supply and hydropower generation, thus this study was done on daily basis.

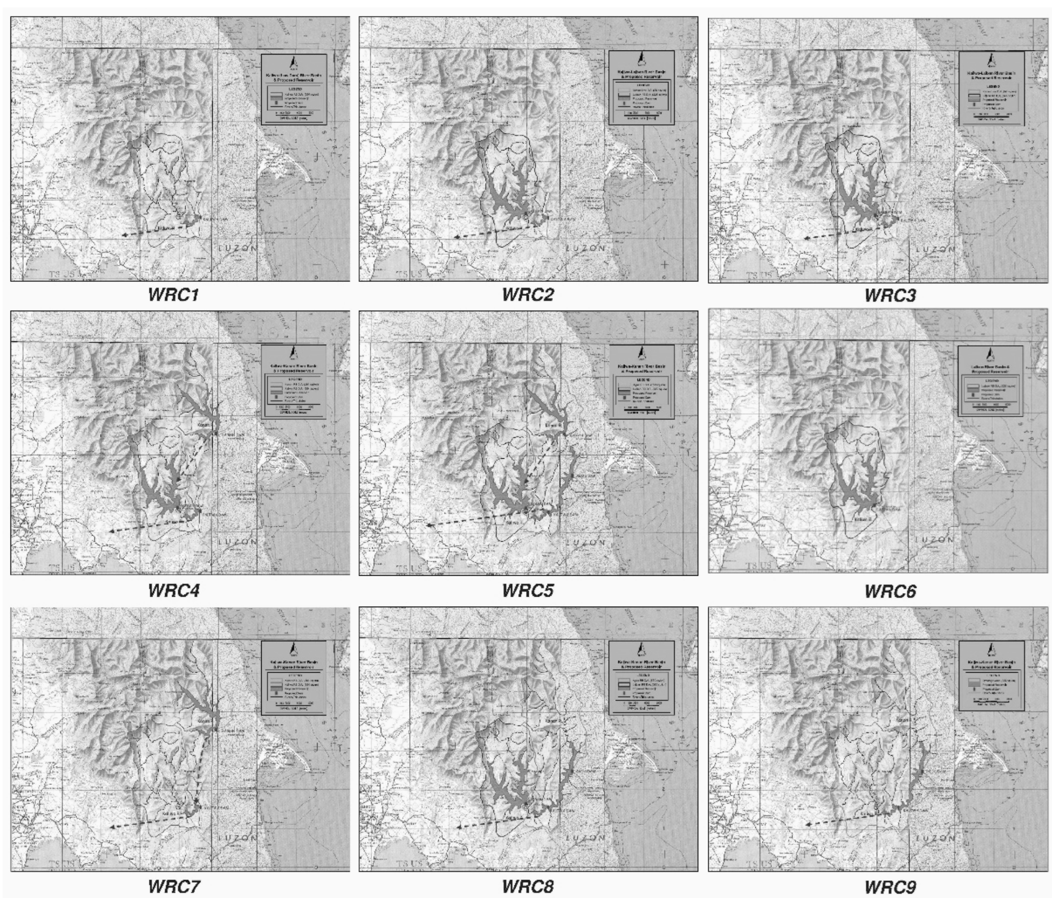

Figure. 5. Alternative water resources configurations in the Agos River Basin with Kaliwa and Kanan Rivers (tributaries of Agos River) composed of combinations of reservoir and/or water conveyance systems (Tabios 2020).

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Figure 6 shows the recommended project sequencing with 85% reliability against projected Metro Manila's water demand for years 2015 to 2050. Kaliwa Low Dam will provide 924 million liters daily (MLD) when completed in 2015, addition of Laiban Dam in year 2020 to provide an additional 603 MLD bringing a total of 1527 MLD, then the Laiban/Kaliwa Dam with Kanan Diversion in 2025, with Kanan Dam in 2028, and finally the Agos Dam in 2035 which will provide a total of 4249 MLD (Tabios 2020). Note that from 2015 to 2035, the Agos River Basin water source has to play catch up with the water demand, which are assumed to be covered by other water sources like those from Laguna Lake, groundwater pumping, and the Angat Dam.

Sustainable Reservoir Development: Case of Pulangi HP IV Reservoir Sediment Flushing Studies

The multipurpose Angat Reservoir/Dam system in Bulacan for domestic water supply, irrigation water supply, hydropower generation, and flood control as well as the multipurpose San Roque Reservoir in Pangasinan for irrigation water supply, hydropower generation, flood control, and water quality control were designed with a finite life of about 70 years due to reservoir sedimentation. Thus, it is not quite a renewable resource and once it gets filled-up, it will be a major effort to decommission or remove it. In addition, a major issue with reservoirs is that it could

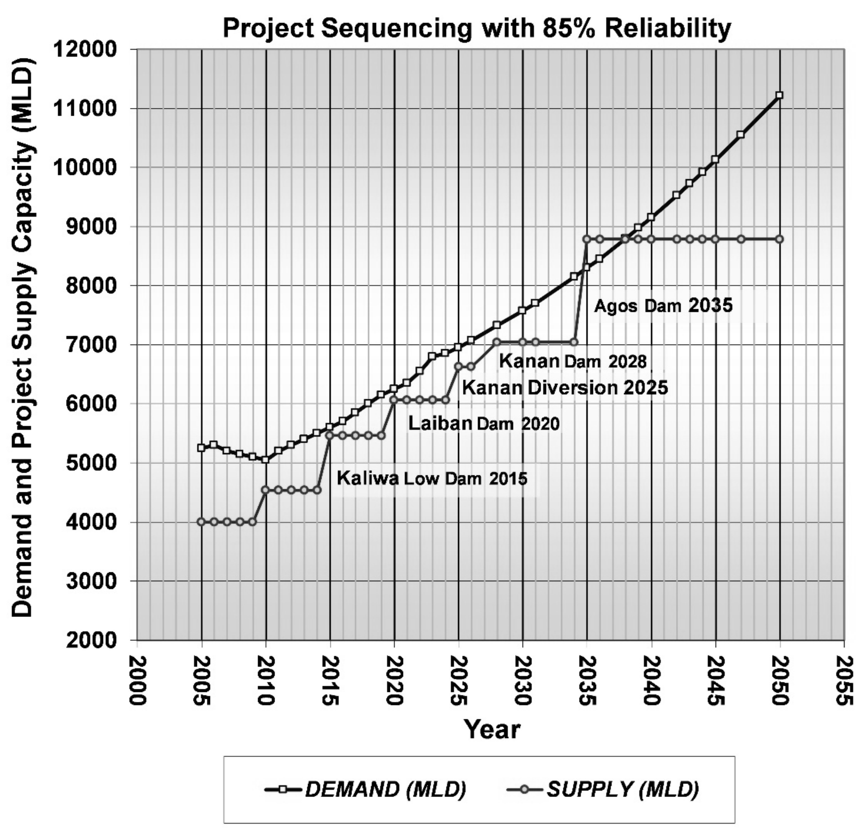

Figure 6. Recommended project sequencing with 80% reliability against projected Metro Manila water demand for years 2015 to 2040 (Tabios 2020).

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adversely impact the river downstream of the dam due to the change (lack thereof) in sediment supply (suspended and bedload), thus altering the natural river landscape (form and alignment) and consequently the downstream river ecology and ecological integrity. In this case, the river downstream will starve from seasonal supply of sediments that is responsible for maintaining stable channels that prevents too much erosion or sedimentation. In any case, there are possible measures or management strategies to minimize such adverse impacts such as the proper location of reservoir site, watershed erosion control, and reservoir sedimentation management strategies that includes sediment flushing or sluicing.

The Pulangi Hydropower Plant (HP) IV reservoir in Maramag, Bukidnon exemplifies a sustainable reservoir design which is the only large-scale reservoir in the Philippines with a sediment flushing facility to prevent or minimize reservoir sediment accumulation. Figure 7 shows sediment flushing operations conducted in Pulangi HP IV reservoir. The left photo shows the start of flushing operations with the opening of the bottom sluice gate (third gated structure from the left) and the right photo shows sediment flushing when both bottom sluice gates have been opened. Figure 8 shows a time series plot of the sediment flushed and reservoir capacity over a 360-day simulation study from (Tabios 2020). The beginning time (in days) is January which started at around 38.5 MCM, approaching around 37.7 MCM in March-April (dry months) and gaining reservoir capacity at about 40 MCM in July-October (wet months) and settling back to 39.3 MCM at the end of the year. A net sediment volume of 0.8 MCM was removed (flushed out) during the 360-day simulation. The Pulangi Reservoir annual sediment inflow is about 1.0 MCM a year, thus if more sediment flushing operations are conducted in a year, the net sediment accumulation will be zero.

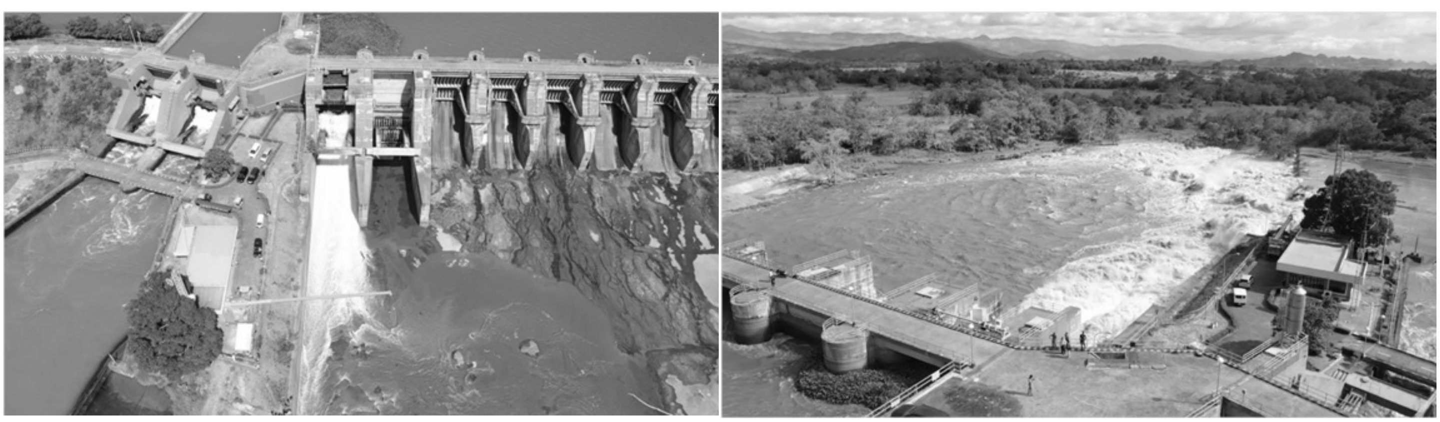

Figure 7. Sediment flushing operations conducted in Pulangi HP IV reservoir. The left photo (looking upstream) shows the start of flushing operations with the opening of the bottom sluice gate (third gated structure from the left) and the right photo (looking downstream) shows sediment flushing when both bottom sluice gates have been opened.

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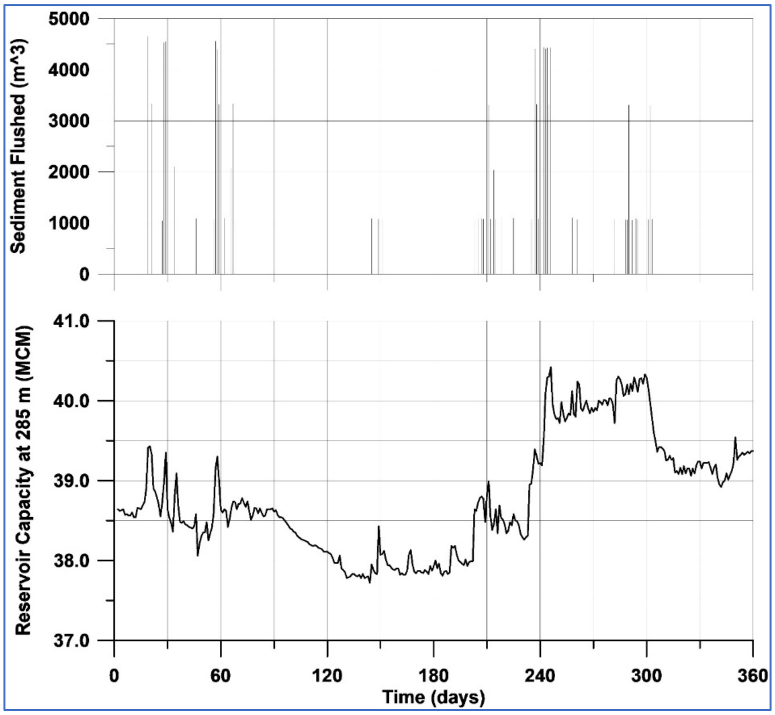

Figure 8. Time series plots of sediments flushed (m3) and reservoir capacity (in MCM, million m3) for a 360-day simulation period with fifty-seven (57) 12-hr flushing operations in Pulangi HP IV Reservoir (Taken from Tabios 2020).

Archetype of Sustainable Engineering Design: Banaue Rice Terraces

This final showcase is Ifugao's ancient Banaue rice terraces as a true archetype of sustainable development and exemplifies the seven fundamental laws of sustainable engineering design as presented by Cuello (2010). In particular, these seven laws of sustainable design taken from the presentation of Cuello (2010) are as follows:

1. Law of Availability: The Ifugao's ancient terraces were designed according to the available terrain, slopes, soil, and water for growing the rice especially the delivery of spring water from the mountain top cascading from one terrace to the next terrace down the mountain.
2. Law of Harmony: The rice terraces are sculpted along the natural contours of the Cordillera Mountains, thus in harmony with nature. Also, the cascade of terraces along slope of the mountain allows for simple delivery and conveyance of spring water located on top of the mountain to all the terraces referred to as functional harmony.
3. Law of Knowledge: Scientific principles of hydraulics were used, enabling the Ifugaos over the millennia to divert stream water for irrigation up to five to six kilometers.
4. Law of Reuse: The roots and stubs of the cut rice plants after harvest are mixed and incorporated into the terrace soil for soil conditioning and fertilizing in preparation for the next planting season.

5. Law of Symbiosis: Rice plants and mudfish were both raised in terrace ponds where the mudfish wastes provide nitrogen and other nutrients to rice plants and mudfishes help protect rice plants by feeding on insects and other pests and in turn, the rice plants supply photosynthetic oxygen and natural habitat to the aquatic environment of the mudfish.
6. Law of Peers: The design of the terraces did not originate from one single individual, but coalesced from the active and sustained exchange of ideas, information, skills, and experiences by a whole community of Ifugaos across generations over at least two millennia.
7. Law of Community: The ancient terraces have become an intimate and integral part of the community's various social, cultural, and religious practices.

CONCLUDING REMARKS

Sustainable water resources development is a complex problem and definitely non-deterministic, dynamic, and uncertain (also called wicked problem) due ecosystem, land use, and climate changes, and uncertainty including economic, social, & political changes.

Thus, understanding and planning for sustainable water resources development encompasses spatio-temporal variations of physical, economic, social, and political factors and must cover infrastructural, institutional, economic, and social resilience, in the context of evolutionary resilience.

In view of this, sustainable water resources development and resilience can no longer be based on traditional science but rather based on sustainability science and that transdisciplinary approach is required which utilizes scientific tools (physical, social, economic, behavioral sciences) and engages stakeholders (academics, professionals, government, civil society) to solve problems through an iterative process of collaborative learning, research, and consensus building.

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