Sustainable Water Resources Development and Resilience

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Outline of Talk

- **Sustainable Water Resources Development**
- **Planning Horizon**
- **Linking Science, Policy and Management through Decision Support Systems**
- **Sustainability Science**
- **Transdisciplinary Approach**
- **Evolutional Resilience**
- **Showcases**
  - ***West Mangahan Lakeshore Dike***
  - ***New Centennial Water Supply Project for Metro Manila***
  - ***Balog-Balog Irrigation Dam Project***
- **Conclusions**

Sustainable Water Resources Development

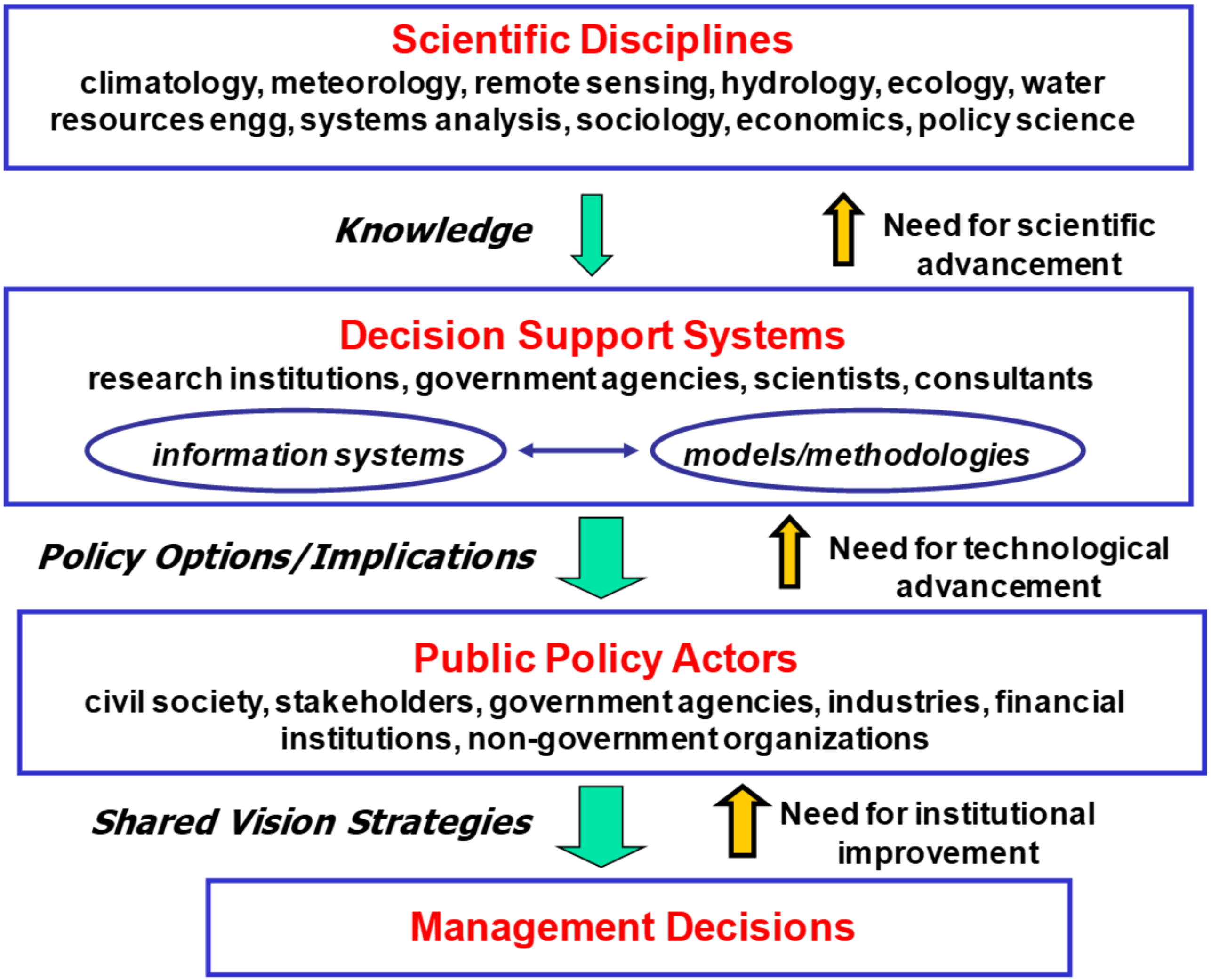
- **The sustainable utilization and development of water resources systems must balance economic development and environmental protection. Economic development is to satisfy basic needs, to alleviate poverty, to enhance economic and social equity, and to improve the quality of human life.**
- **Environmental protection is to ensure ecological integrity of the environment and to maintain biodiversity, biological productivity and ecological resilience.**
- **Planning and management for sustainable water use and development is both a technical and governance challenge.**
- **There is the need to reconcile the competing ecological-social-economic objectives of the various actors (government, stakeholders, professionals, academics, advocates) with long-term perspectives and policy frames into short-term, actions and management decisions.**

Planning Horizon for Sustainable Water Resources Development

- Water resources planning and management studies should be conducted in the context of sustainable development. Ideally, these studies should cover periods of 100 to 150 years (planning horizon) encompassing 2 to 3 generations.
- In this case, future scenario setting as far as land use plans, economic developments, demographic change including climate change will be important to such planning studies.
- For instance, assessment studies on watersheds with proposed building of large-scale, urban centers in the countryside, conversion of farmlands into residential subdivision or industrial zones that balances economic development and ecological integrity of the water resources system will be required.

Linking science (research-based and experience-based knowledge) and public policy & management decisions in the pursuit of sustainable water resources management.

[After from Georgakakos, 2004]



Sustainable Water Resources Development in the Context of Sustainability Science vs. Traditional Science

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 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.

Columns 1-4 Adapted from Prof. H. Yoshikawa, (Sustainability Science for Action, 2009)

Transdisciplinary Approach in Sustainable Water Resources Development

- **Sustainable water resources development is a complex process due to the interaction, dynamics and uncertainties of:**

Ecological system	*Economical system*	*Socio-political system*
• global and local climate extremes and variabilities • changes in physical configuration and dimensions	• economic objectives • Benefits, costs and externalities • Investments and financing	• societal objectives • social norms and traditions • culture of disaster • political ambitions

- **Thus, sustainable water resources development encompass 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 nondisciplinary ideas and theories"

Features of Transdisciplinary Approach

- **stakeholder engagement and collaboration** involving academics, professionals, government units, non-government organizations, communities and individuals

- **iterative process** of project development in consultation with stakeholder

- **work collectively** from problem identification, then knowledge generation to development of sustainable solutions and final project implementation

- **decisions are made on hierarchical and panarchical basis** of (i) satisfying physical laws and constraints, (ii) sustainable ecological solution, (iii) sound economic basis, (iv) socially justifiable, and (v) politically acceptable solutions

Transdisciplinary Approach and Other Disciplinarities

Monodisciplinary
- reactive
- isolated approach by individual experts

Multidisciplinary
- proactive
- additive approach bringing together a wide range of experts

Interdisciplinary
- integrative
- experts and stakeholders solve a problem by parts then integrate

Transdisciplinary
- interactive and holistic
- experts and stakeholders solve problem as a whole through interaction of parts

Approaches to Building Resilience for Sustainable Water Resources Development *(Prof C.S. Holling 1973, Canadian theoretical ecologist in Davoudi et al, 2016)*

- **Engineering resilience**
  - **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**
  - **the faster the system bounces back to a single, stable equilibrium, the more resilient it is.**
- **Ecological resilience**
  - **ability to absorb and persist before the system changes its structure and ability to adapt to disturbance recognizing the existence of multiple equilibria, and possibility of systems to flip into alternative stability domains.**
- **Evolutionary resilience**
  - **the ability of a ecological-socio-economic system to change, adapt and transform in response to perturbations and disturbances and that system is not conceived to return to normality.**
  - **it acknowledges that systems are complex, nonlinear and self-organizing permeated by uncertainty and discontinuities.**

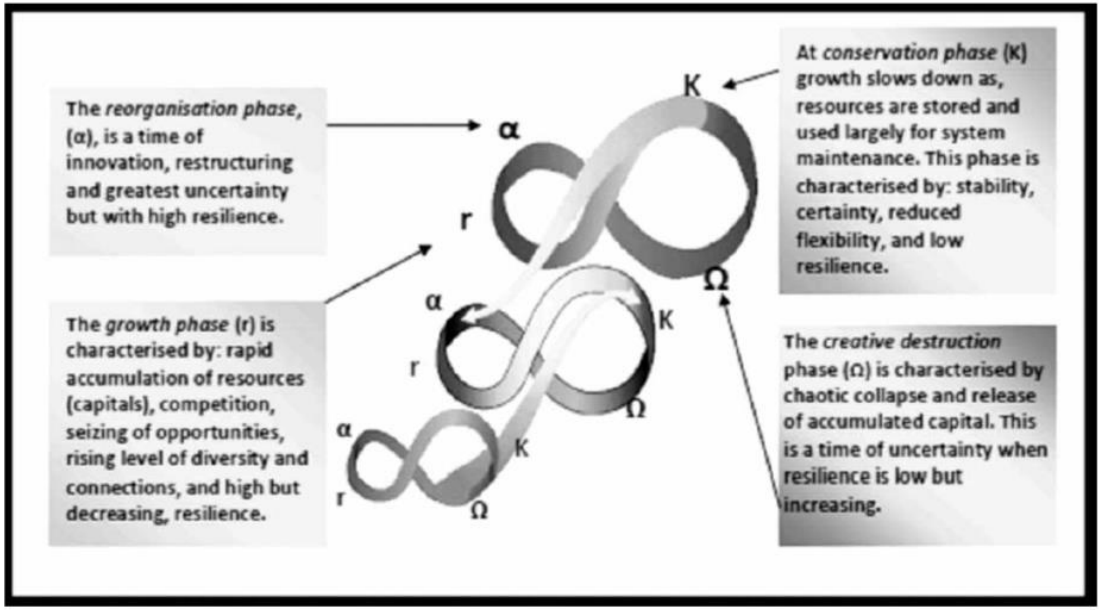
Evolutionary resilience in the context of Holling's panarchy model of adaptive change *(Davoudi et al, 2016)*

Four phases:

- Growth: high but decreasing resilience
- Conservation: low resilience
- Creative destruction: increasing resilience
- Reorganization: opening up of new and unpredictable possibilities.

This implies that:

- as systems mature, their resilience reduces and they become "an accident waiting to happen" , and
- when systems collapse, "a window of opportunity" opens up for alternative systems configuration.



Holling uses the "omega" symbol for the creative destruction phase to denote the end phase, but one which is rapidly followed by an alpha phase of reorganization and renewal.

The omega phase is, therefore, the time of greatest uncertainty yet high resilience; a time for innovation and transformation; a time when a crisis can be turned into an opportunity.

Qualities of Resilience and Resilient Systems (from Arup, 2012)

Reflective
- People and institutions systematically learn from experience, with an adaptive planning mindset that accepts unpredictable outcomes

Robust
- A robust system anticipates system failures and makes provisions to maximize predictability and safety.

Redundant
- Redundancy is to deliberately plan capacity so that if one component of the system fails, other pathways or substitutable components can meet essential functional needs.

Flexible
- Flexibility is the ability to change, evolve and adopt in response to changing conditions.

Resourceful
- Resourcefulness is to respond quickly to extreme events, modifying organizations or procedures as needed.

Inclusive
- An inclusive approach is consultation and engagement of stakeholders and communities, particularly those who are vulnerable.

Integrated
- Integration requires ongoing feedback system for collection of information and response.

Resilience Planning
(Brown, Dayal & del Rio, 2012)

Resilience planning brings together technical, scientific, and local knowledge into decision making processes.

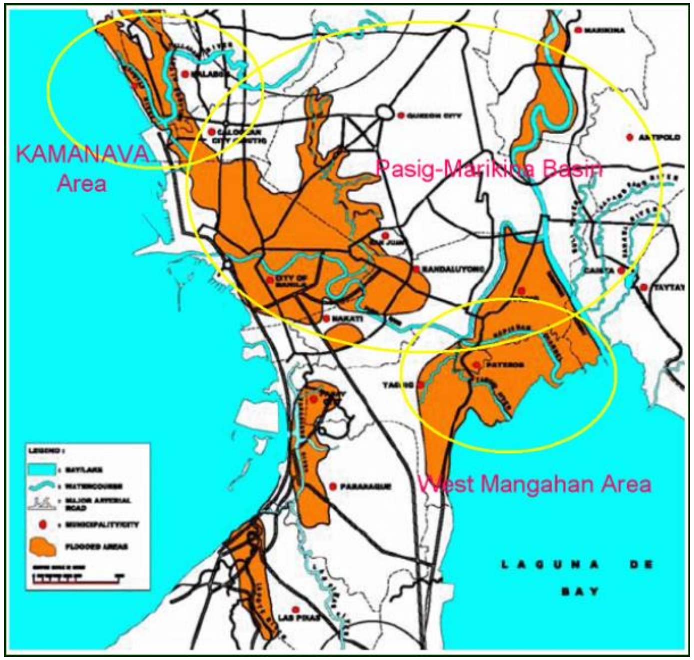
Engages multiple stakeholders using an adaptive cycle of action and reflection progressively learning as you do it and doing as you learn.

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-economic and climate.

It involves visioning and scenario planning considering future urbanization, land use and hydrometerologic-climate uncertainty.

Note: Sustainability Science, Transdisciplinary Approach and Resilience Planning are all parts and parcel of Sustainable Water Resources Development

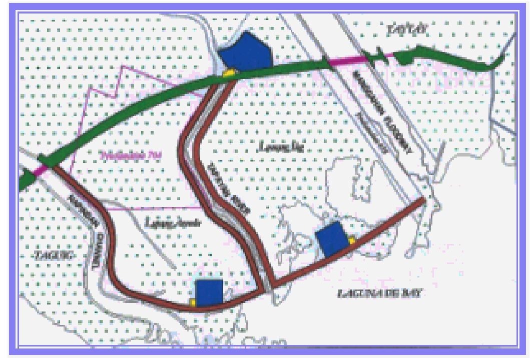
West Mangahan Road Dike Project



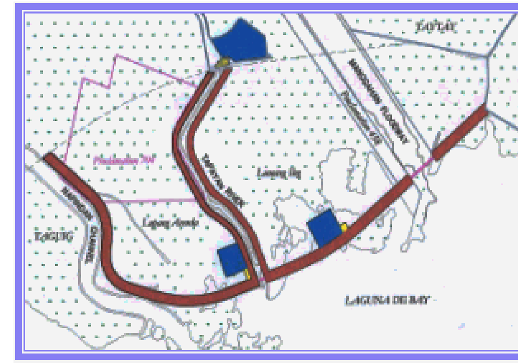
- Metro Manila, floodwaters from Marikina River instead of going straight to Manila, are diverted to Laguna Lake through the Mangahan Floodway for temporary storage.
- However, flooding occurrences along the north lakeshore towns of Taguig and Taytay became more frequent since the construction of the 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 stakeholder that include fishermen, farmers, businesses, and lakeshore residents on the proposed lakeshore dike alignment.
- This study was undertaken to review and conduct value engineering that resulted in evaluating six (6) alternative lakeshore dike configurations that were formulated through a series of 8 stakeholder consultations.

Alternative Lakeshore Dike Configurations from Stakeholder Consultations

- ***Considers full protection of human settlements through polder dikes but obliterating fish spawning area***

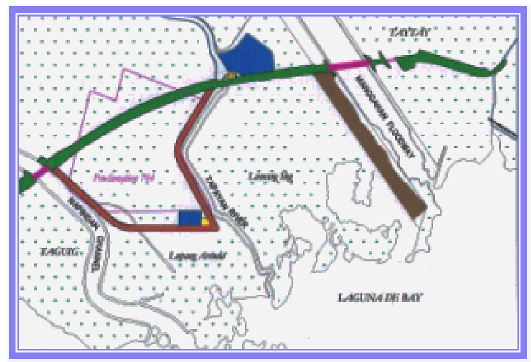


Alternative 1A

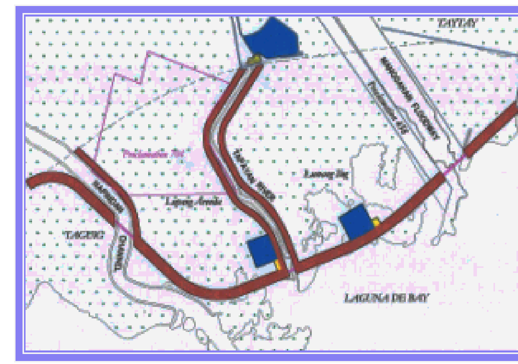


Alternative 2A

- ***Considers partial protection of human settlements and retain fish spawning area***

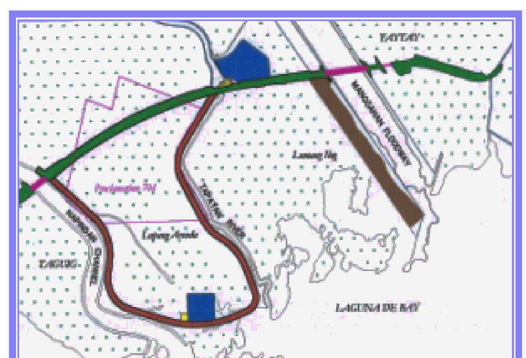


Alternative 1B

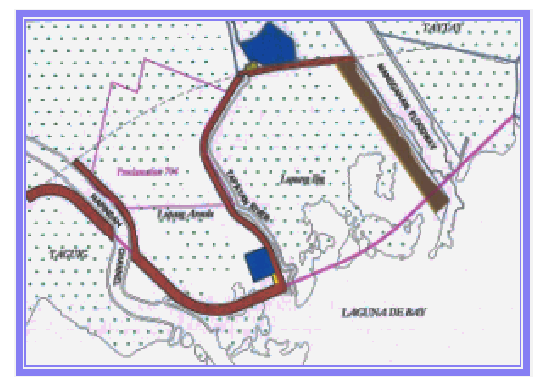


Alternative 2B

- ***Full protection of human settlements and retention of fish spawning area with combination of road dike and bridges***



Alternative 1C



Alternative 2C

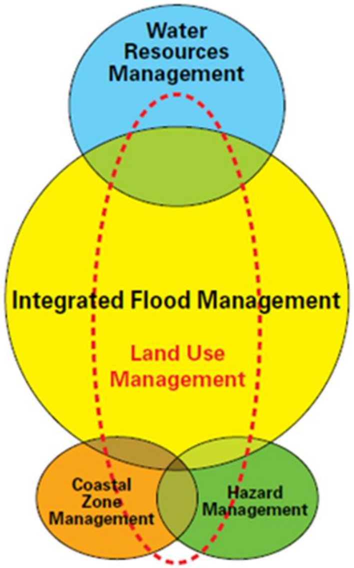
Results of 2-d flood inundation model simulations at four (4) selected areas in West Mangahan for the six (6) flood plans.

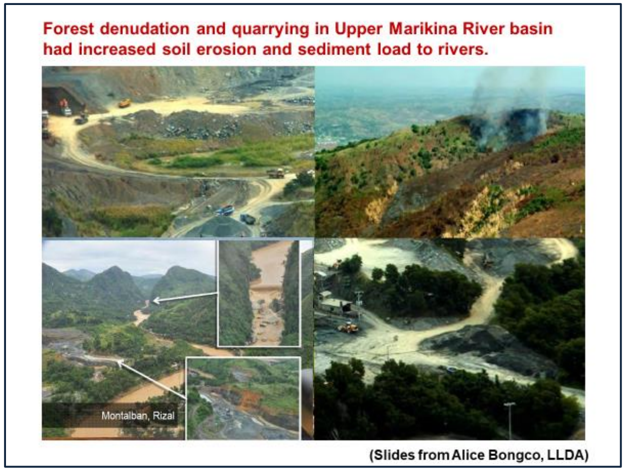
Project Alternatives	*Area 1 North of Arenda Area*	*Area 2 North of Lumang Ilog Area*	*Area 3 Arenda Area*	*Area 4 Lumang Ilog Area*
1A				
Ave Depth (m)	**2.095**	**1.079**	**0.086**	**2.051**
% Area Flooded	**100**	**79**	**63**	**100**
1B / 3				
Ave Depth (m)	**2.282**	**1.204**	**0.881**	**1.428**
% Area Flooded	**100**	**88**	**85**	**100**
1C				
Ave Depth (m)	**1.895**	**0.895**	**0.086**	**1.431**
% Area Flooded	**100**	**75**	**63**	**100**
2A				
Ave Depth (m)	**2.115**	**1.077**	**0.086**	**2.025**
% Area Flooded	**100**	**77**	**63**	**100**
2B				
Ave Depth (m)	**2.118**	**1.079**	**0.086**	**2.028**
% Area Flooded	**100**	**77**	**63**	**100**
2C				
Ave Depth (m)	**1.894**	**0.893**	**0.086**	**1.432**
% Area Flooded	**100**	**73**	**63**	**100**
No Lakeshore Dike				
Ave Depth (m)	**2.429**	**1.267**	**2.243**	**2.085**
% Area Flooded	**100**	**100**	**100**	**100**
No Taytay Dike				
Ave Depth (m)	**2.349**	**1.193**	**2.164**	**2.012**
% Area Flooded	**100**	**100**	**100**	**100**

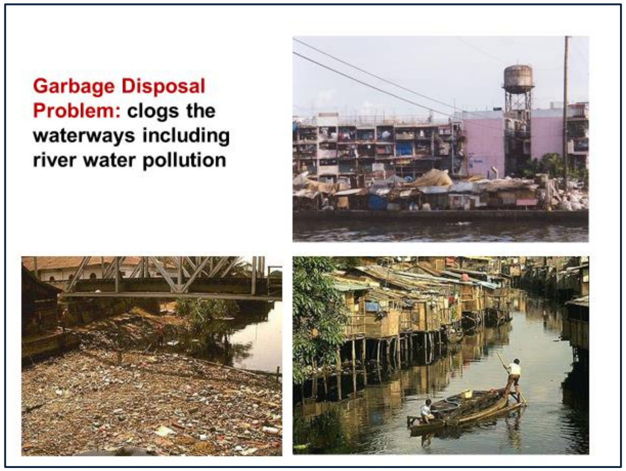
Results of Social, Environmental and Economic Analysis

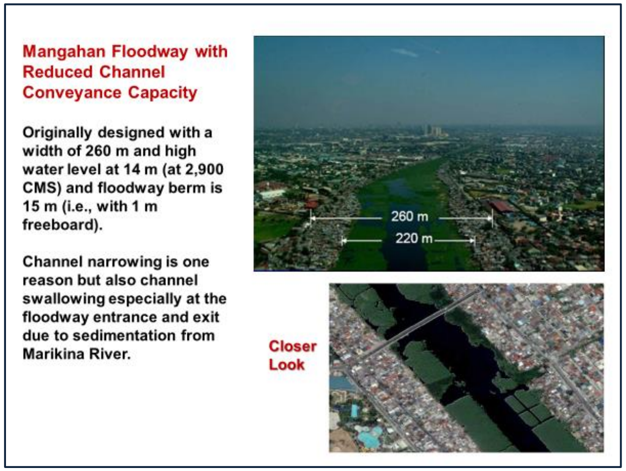
ALTERNATIVE		Directly Affected		Unprotected Families	Degree of Environmental Impact	Cost	EIRR
		Structures	Families			PhP (Million)	(%)
Lakeshore Dike (Original Alignment)		1,613	1,830	11,878		325	
1A	Original Alignment with Polder Dikes	2,000	2,639	-	HIGH	876	Negative Return
1B	Original Alignment with Polder on Proclamation 704 and Proclamation 458 on fill	2,345	2,661	-	LOW	568	8.59
1C	Original Alignment with Polder on Lupang Arenda Delta & Proclamation 458 on fill	2,345	2,661	-	MEDIUM	659	5.48
2A	Realignment from East Napindan to West Manggahan	1,310	1,425	-	HIGH	873	1.10
2B	Realignment from West Manggahan to West Napindan	1,179	1,307	-	HIGH	930	Negative Return
2C-2	Realignment at West Manggahan with Viaduct along Lumang Ilog Delta and Proclamation 458 on fill	1,283	1,403	-	MEDIUM	1,109	Negative Return

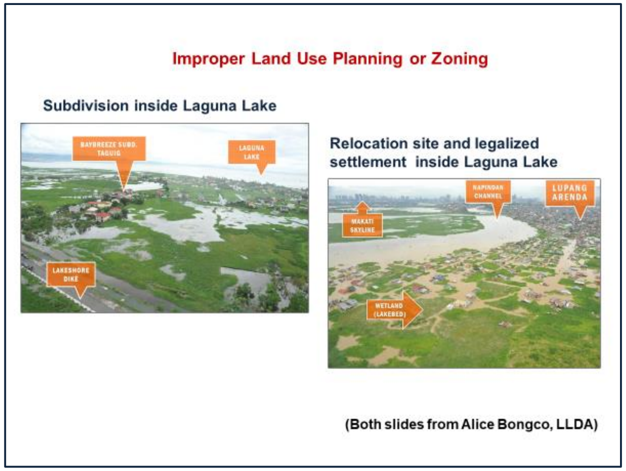
Flooding Issues in Marikina River System and the Need for Holistic Flood Management for Sustainable Water Resources Management







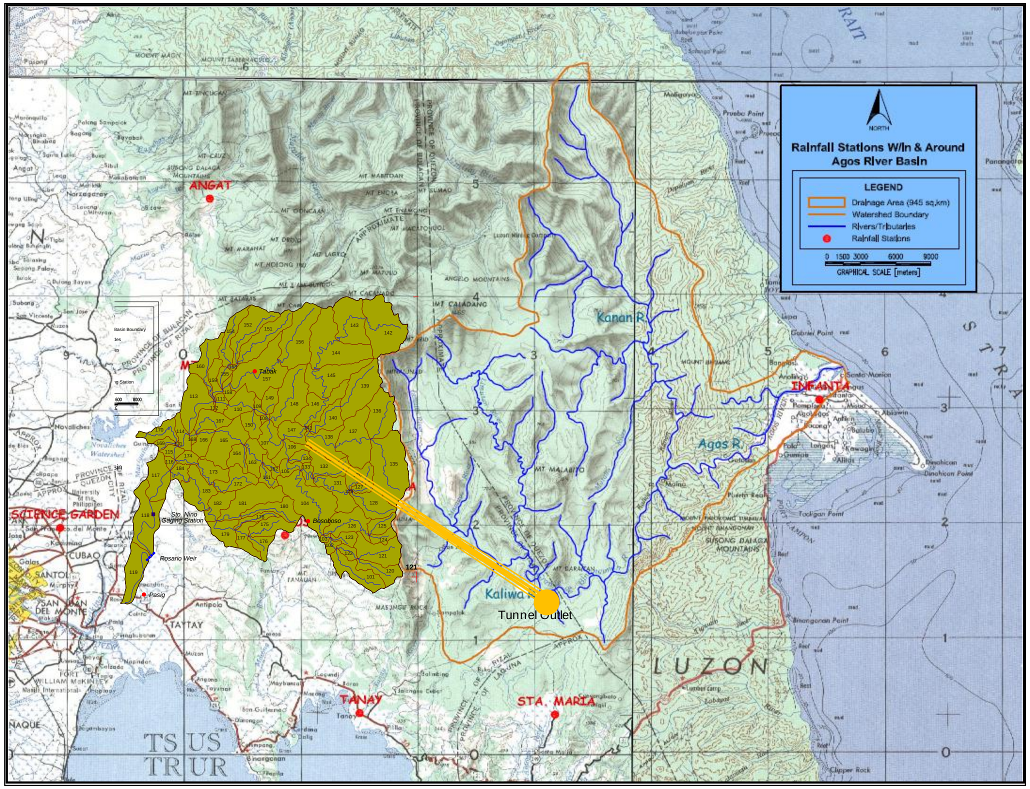


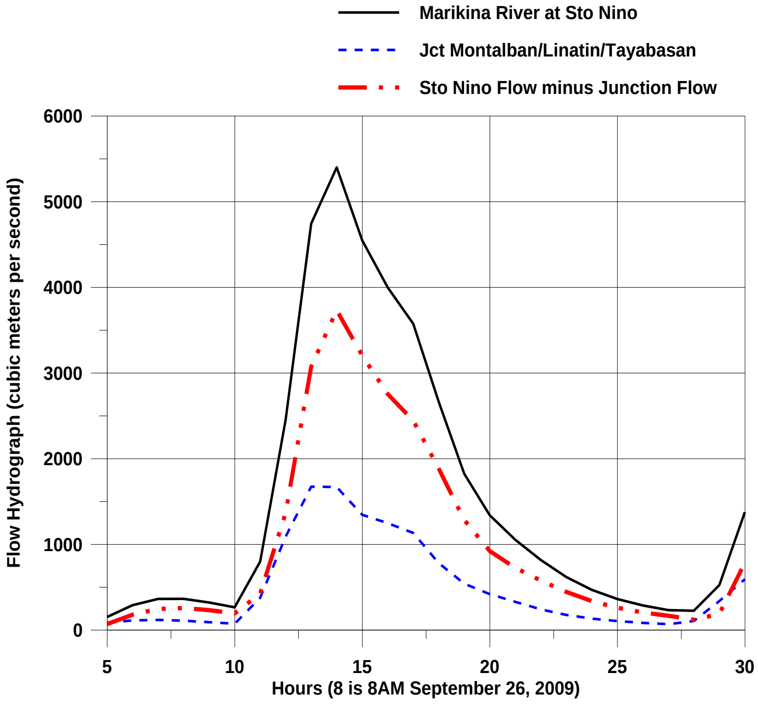


Marikina River Stormwater Tunnel to Agos River Basin or Pacific Ocean

This is to divert 30-40% of Marikina River flows to Pacific Ocean instead of flowing directly into Pasig River or temporarily stored in Laguna Lake. De-creates flooding problems in Manila and towns along Pasig River and Laguna Lake. Remember Manila was built in the Pasig Delta (wetlands or swamplands)

Tunnel Diameter (m)	Dam Height at Diversion Point (m)	Effective Head (30 m + dam height)	Channel Slope	Flow Capacity (m^3/sec)
10	15	45	0.0016	1460
10	20	50	0.0018	1540
10	25	55	0.0020	1615
10.5	5	35	0.0013	1467
10.5	10	40	0.0014	1570
10.5	15	45	0.0016	1664
11	5	35	0.0013	1660
11	10	40	0.0014	1776



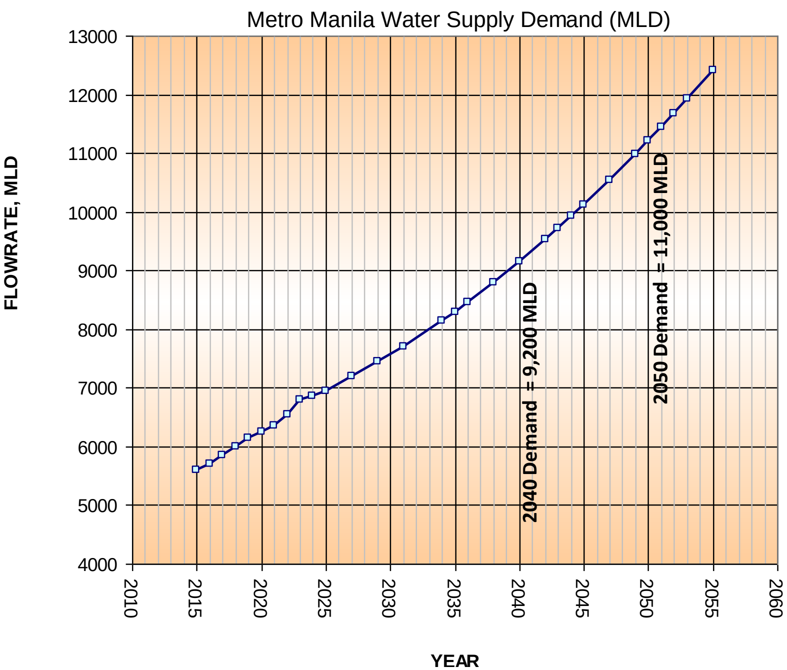


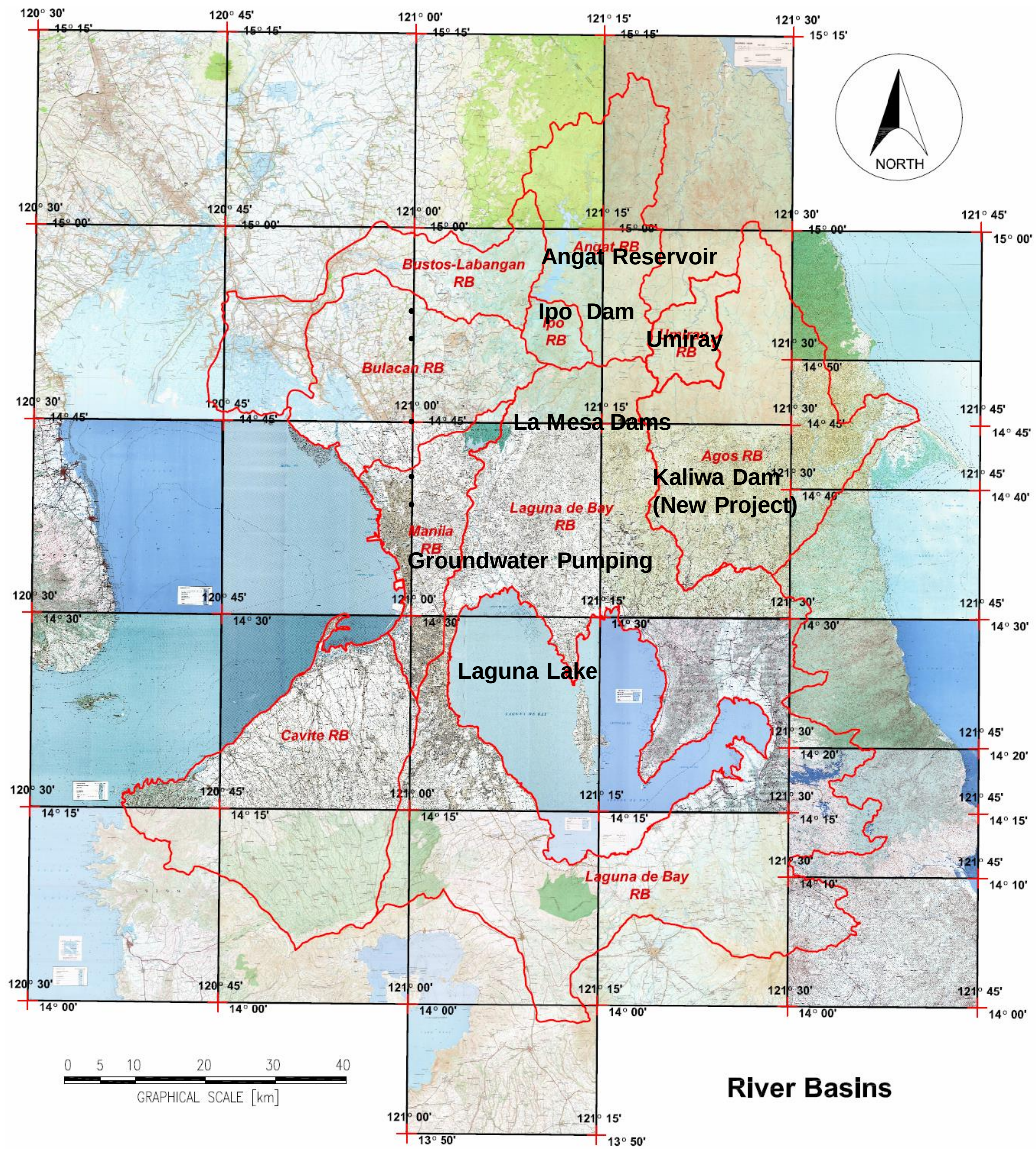
New Centennial Water Supply Project for Metro Manila

Current Water Supply Sources and Projected Water Demand of Metro Manila

- **Angat Reservoir including Ipo and La Mesa Dams and Umiray Transbasin Transfer (supplies 4200 MLD)**
- **Laguna Lake (200>300 MLD)**
- **Groundwater (780 MLD)**

Total Supply = 5180 MLD
2015 Demand = 5600 MLD
***Deficit* = 420 MLD**

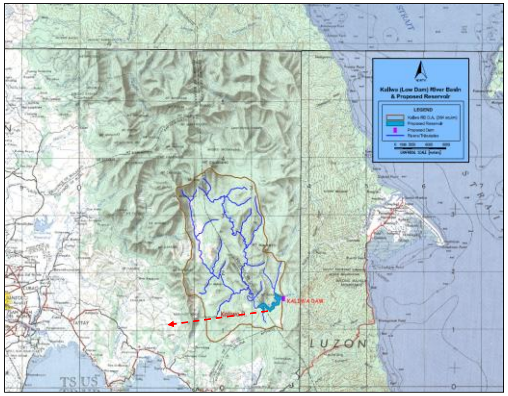




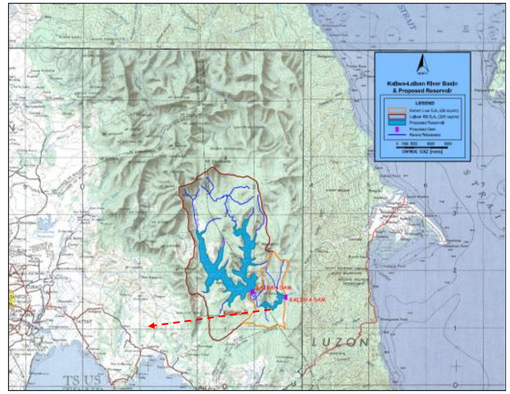
Historical Background

- In 1972, Laiban Dam in the Kaliwan River basin was identified as an alternative water source of Metro Manila.
- In the early 1980's, Laiban Dam project started and 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 Pres. Ramos, Estrada and Macapagal but there were various obstacles especially funding and resettlement issues then.
- In 2012, President Aquino revived the project since Metro Manila's water supply has become critical due to increasing water demand.
- Also, aside from future water security, this project is for redundancy since Metro Manila cannot simply rely on Angat Reservoir as sole source of 85% of Metro Manila's water use.
- Thus, for sustainable water source of Metro Manila, this study was to conduct long-term reliability analysis and project sequencing & staging of various river/reservoir/dam configurations in the Kaliwa-Kanan-Agos River Basin to augment Metro Manila's water supply including hydropower generation and flood control function.

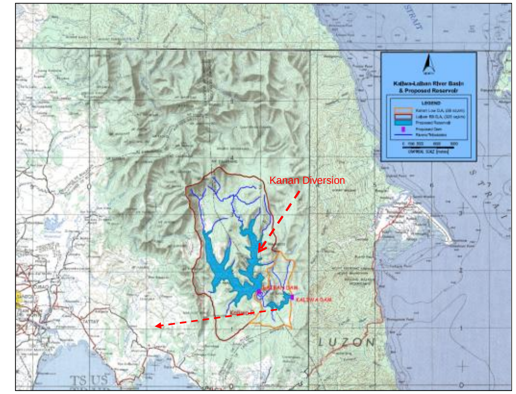
9 Alternative Water Resources System Configurations for Simulation-Optimization Studies



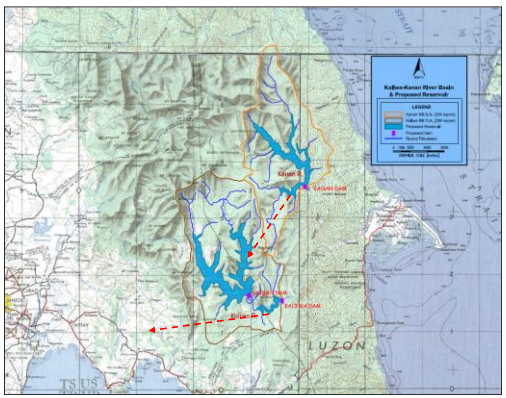
WRS 1: Kaliwa Low Dam (Thru Kaliwa – Baras or Tanay Transfer Facilities)



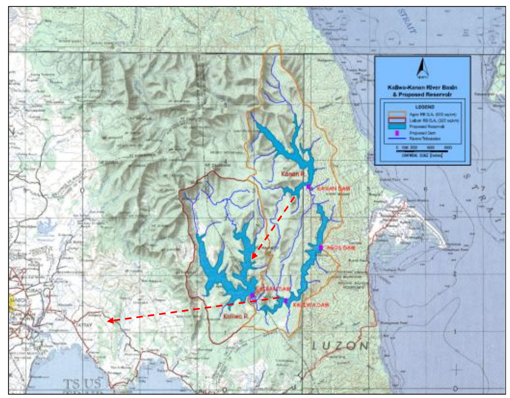
WRS 2: Kaliwa Low Dam and Laiban Dam (Thru Kaliwa – Baras or Tanay Transfer Facilities)



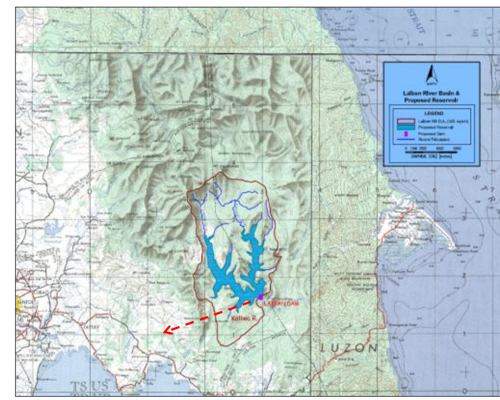
WRS 3: Kaliwa-Low & Laiban Dams & Kanan Diversion (Thru Kaliwa – Baras or Tanay Transfer Facilities)



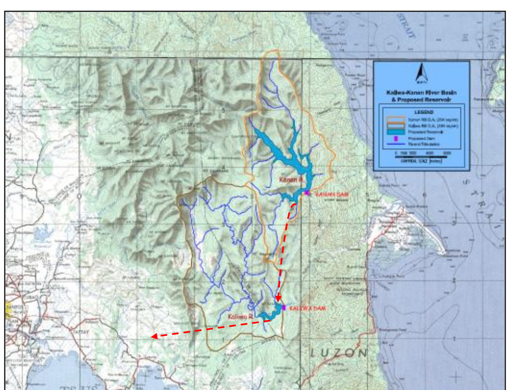
WRS 4: Kaliwa Low, Laiban & Kanan Dams (Thru Kaliwa – Baras or Tanay Transfer Facilities)



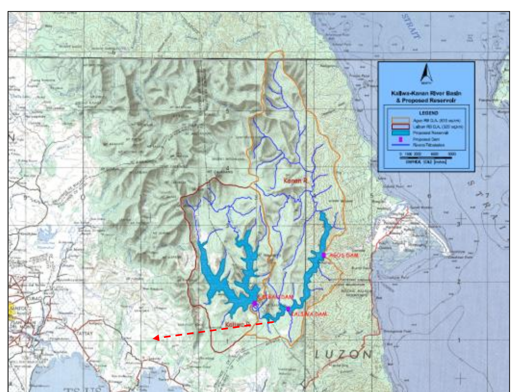
WRS 5: Kaliwa Low, Laiban, Kanan & Agos Dams (Thru Kaliwa – Baras or Tanay



WRS 6: Laiban Dam Only (Thru Kaliwa – Baras or Tanay Transfer Facilities)



WRS 7: Kaliwa Low & Kanan Dams (Thru Kaliwa – Baras or Tanay Transfer Facilities)



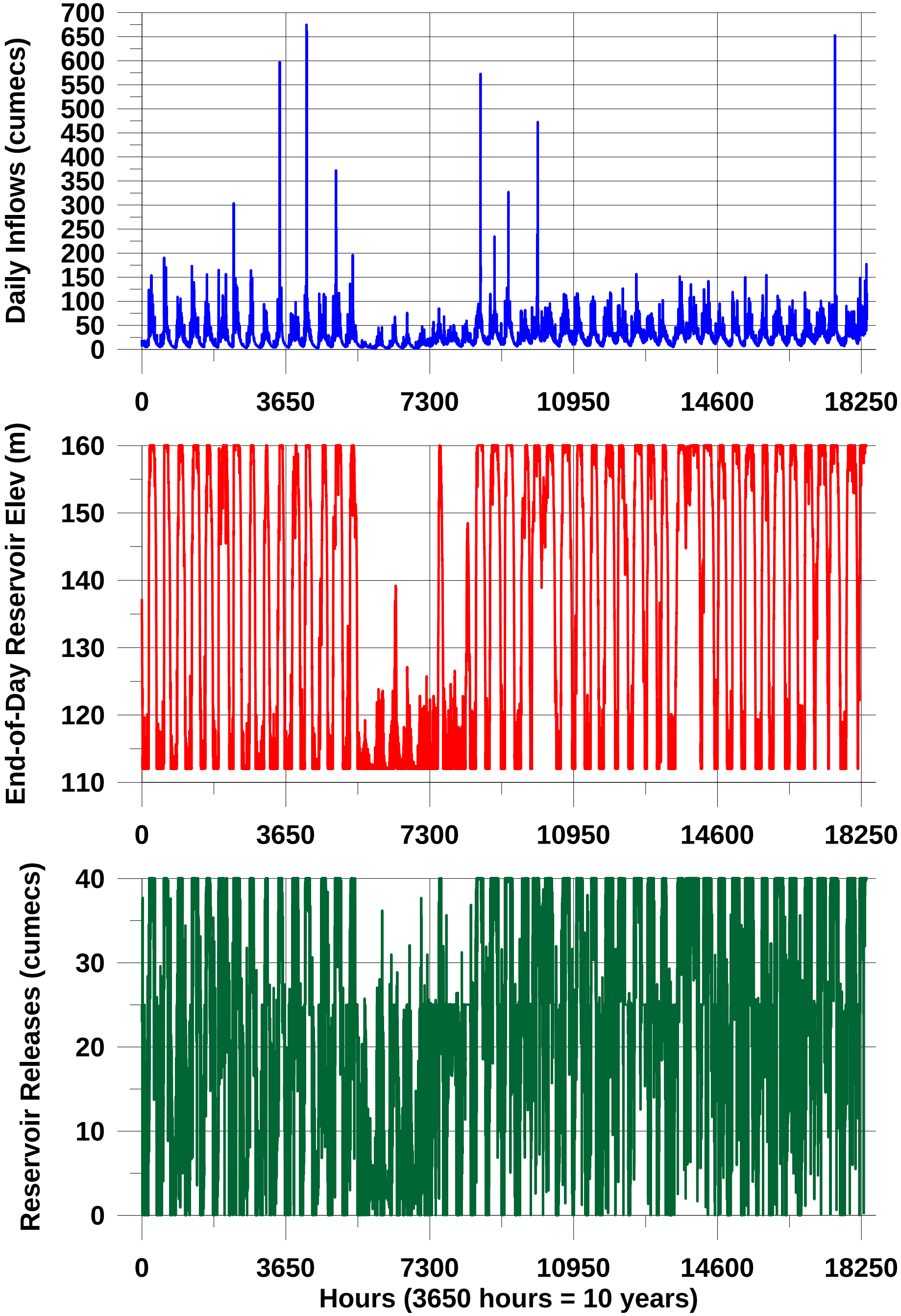
WRS 8: Laiban Dam & Agos Dam (Thru Kaliwa – Baras or Tanay Transfer Facilities)

WRS 9: Kaliwa Low & Agos Dams (Thru Kaliwa – Baras or Tanay Transfer Facilities)

50-Years Reservoir Optimization-Simulation Runs

Kaliwa Low Dam
Dam Elevation = 160 m
Dam Height = 53 m
Flow Demand = 15 CMS

Time Series Plots



Reliability Analysis of Laiban Dam and Kaliwa Low Dam (50 Years Optim-Simul Runs)

Laiban Dam 93 m

Cases	*Target Release (CMS)*	*Water Supply Reliability (MLD)*		
		50%	*80%*	*85%*
1	*20/15*	1555	549	403
2	*20/20*	1602	898	694
3	*20/25*	1668	899	657
4	*25/15*	1642	534	408
5	*25/20*	1637	561	395

Cases	*Target Release (CMS)*	*Power Reliability (MW)*		
		40%	*60%*	*80%*
1	*20/15*	40.39	23.90	8.90
2	*20/20*	42.10	34.55	17.68
3	*20/25*	40.88	29.43	14.60
4	*25/15*	37.02	21.76	7.89
5	*25/20*	41.35	25.05	8.76

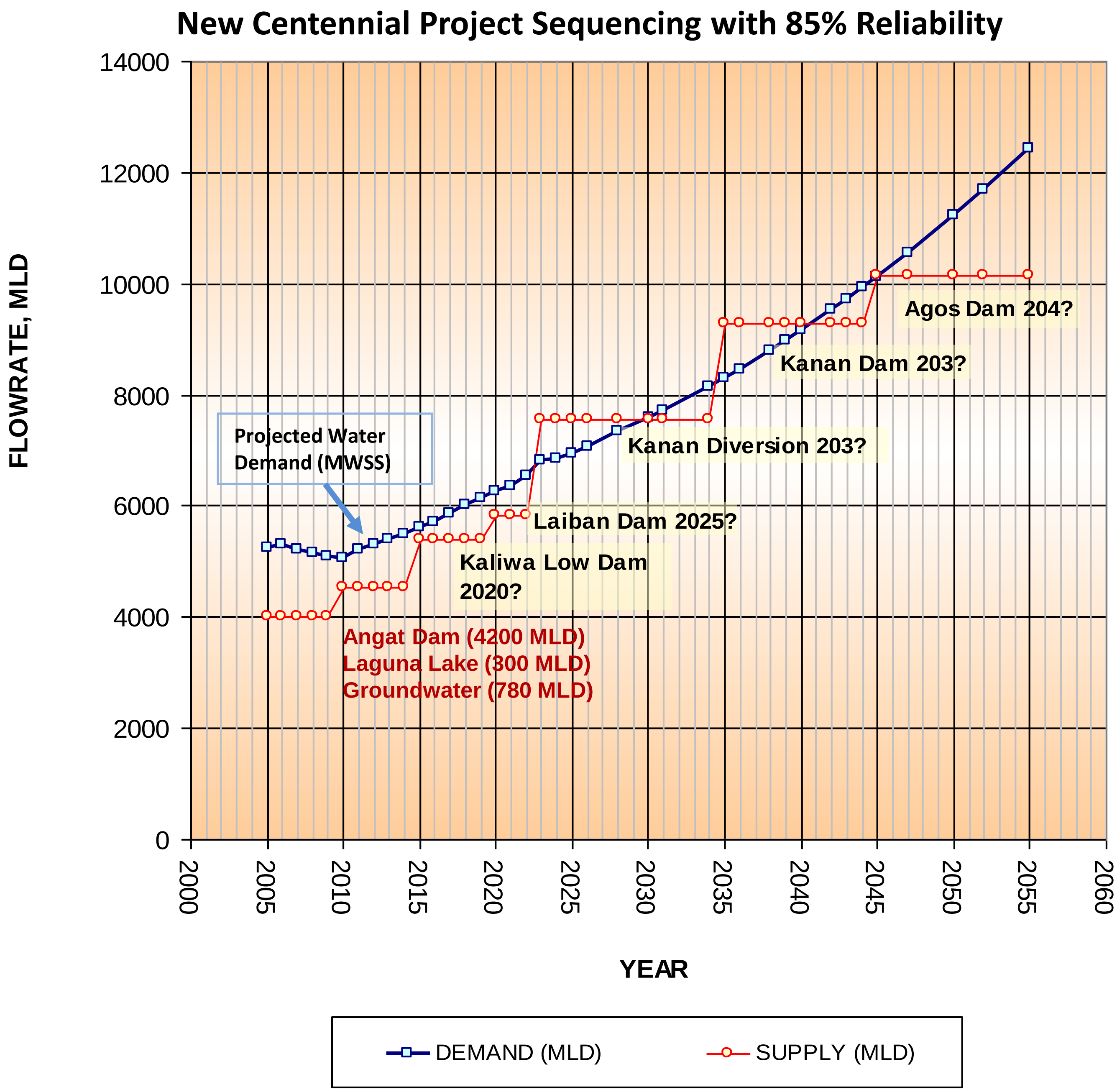
Kaliwa Low Dam 53 m

Cases	*Target Release (CMS)*	*Water Supply Reliability (MLD)*		
		50%	*80%*	*85%*
1	*20/15*	2152	1296	260
2	*20/20*	1926	1655	1527
3	*20/25*	2263	1724	1385
4	*25/15*	2335	1296	1251
5	*25/20*	2119	1441	1141

Cases	*Target Release (CMS)*	*Power Reliability (MW)*		
		40%	*60%*	*80%*
1	*20/15*	36.78	25.45	15.50
2	*20/20*	30.46	26.33	22.20
3	*20/25*	34.70	30.56	16.53
4	*25/15*	38.75	27.58	15.69
5	*25/20*	34.95	26.27	16.11

Notes:

- **Target release is desired release imposed in the optimization. In Case 1, 20/15 target release means 20 CMS for Laiban Dam and 15 CMS for Kaliwa Low Dam.**
- **The results show that the optimum target release is Case 2 (20/20) which implies that an aggressive reservoir release rule (high target release) will result in less flow reliability. However, too passive release rule result in lower firm water yield but higher reliability at higher percent-of-time.**
- **The releases at Laiban Dam goes to Kaliwa Low Dam so only the water supply reliability of Kaliwa Low Dam is meaningful to deliveries to Metro Manila.**
- **The hydropower generated are separate for Laiban and Kaliwa Low Dams so that for Case 2 at 60% reliability, the total is 72.56 MW.**



New Centennial Project Sequencing with 85% Reliability
FLOWRATE, MLD
14000
12000
10000
8000
6000
4000
2000
0
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
2055
2060
YEAR
Projected Water Demand (MWSS)
Agos Dam 204?
Kanan Dam 203?
Kanan Diversion 203?
Laiban Dam 2025?
Kaliwa Low Dam 2020?
Angat Dam (4200 MLD)
Laguna Lake (300 MLD)
Groundwater (780 MLD)
DEMAND (MLD)
SUPPLY (MLD)

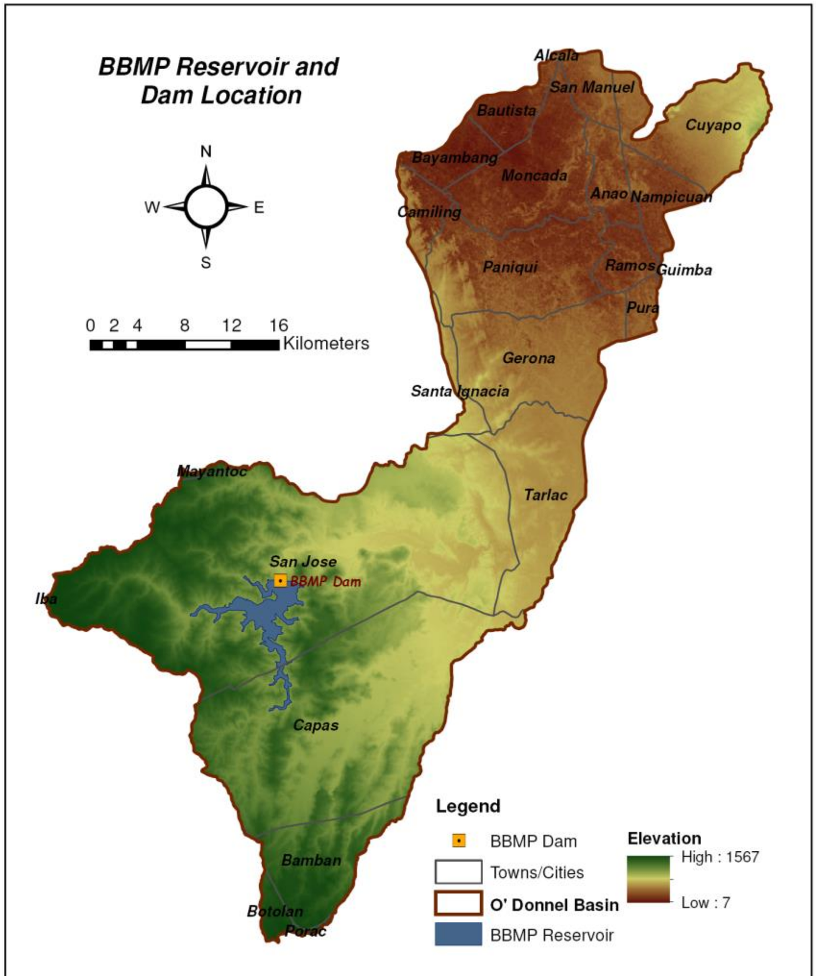
Single High Dam versus Multiple Dam System for Balog-Balog Irrigation Project with Hydropower and Flood Control Function

- The Balog-Balog Irrigation System project consists of Phase I to irrigate 12,475 ha and Phase 2 for 21,935 ha, thus a total area of 34,410 ha.
- The Balog-Balog Multipurpose Dam was first conceived during the presidency of Cory Aquino around 1987 and it got NEDA-ICC approval in February 1988 for 2.712B funding from Italian government.
- However, in 1991, the irrigated area drastically reduced to less than 1,000 ha after the Mt. Pinatubo eruption since massive amounts of lahar were deposited in the Tarlac River diversion dam as source of irrigation water then.
- To rehabilitate the Balog-Balog Irrigation system, the Italian government renegotiated the loan for 8.064B with NEDA-ICC approval in January 1992. However, this did not push through and then in February 2000, Japan negotiated a special Yen loan for 12.064B with NEDA-ICC approval for the third time.

- **All along, Balog-Balog Multipurpose, Single High, Dam was never constructed due to some issues and questions on irrigation water yield, reservoir sedimentation storage allocation, spillway design capacity, flood benefits, fish density and benefits, hydropower generation.**
- **Then, in 2012, TWEDCO, a joint venture, proposed the Balog-Balog Multiple Dam System which consists of cascade of 19 low dams in the Bulsa River and O'Donnell River watersheds as an alternative to a single high dam proposed by NIA.**
- **Thus, this study was to compare the proposed Balog-Balog multipurpose single, dam (BBMP) versus the proposed multiple dam system project (BBMDS) through reliability analysis in their ability to deliver irrigation water supply and hydropower generation considering reservoir sedimentation as well as their possible flood control function.**
- **Watershed streamflow generation and reservoir optimization-simulation studies were conducted over 50 years of data.**

Balog-Balog Multipurpose Single, High Dam Project

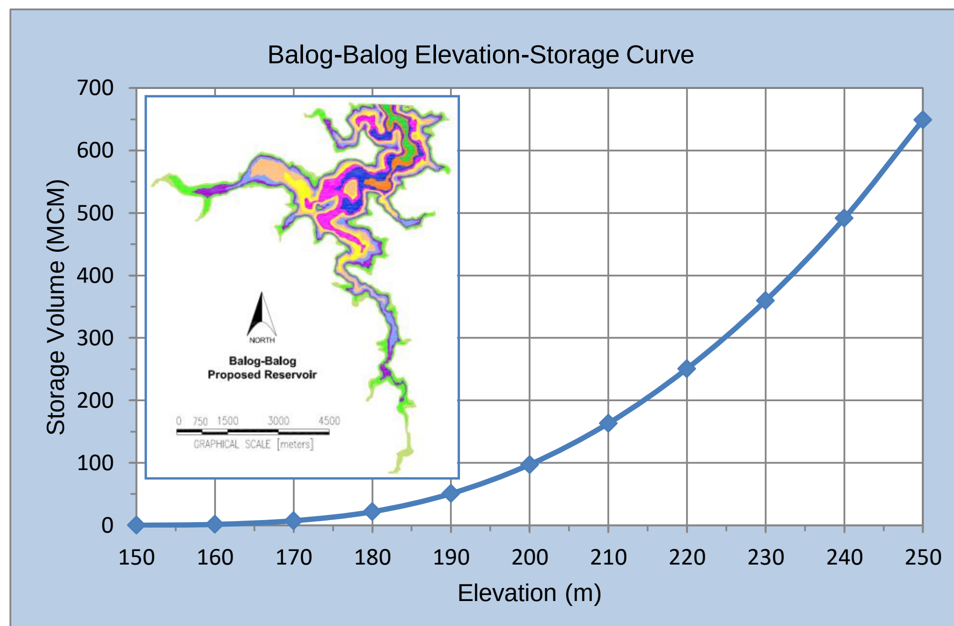
The scheme is straight-forward which is to build a single reservoir with high dam to supply the irrigation needs of Balog-Balog Irrigation System with an estimated service area of about 34,000 ha.



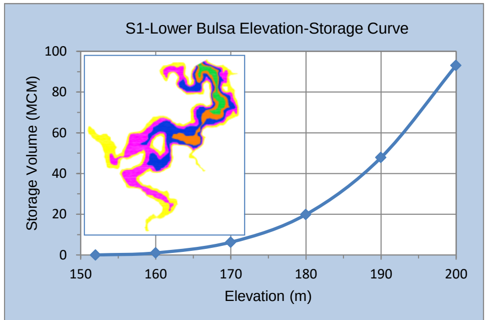
Balog-Balog Elevation-Area-Storage Data

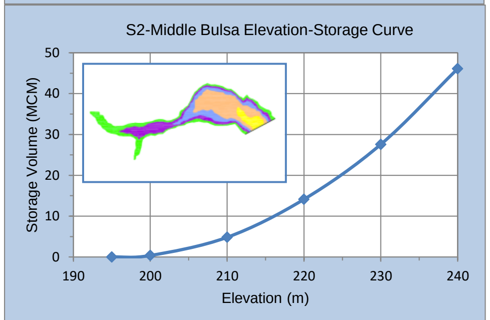
Spillway Elevation (m): 245
Min. Dam Base Elev (m): 150
Design Spillway Height (m): 95

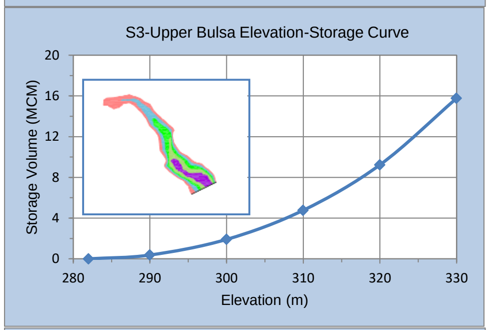
Elevation (m)	Height (m)	Surface Area (m^2)	Res Storage (m^3)	Res Storage (MCM)
150	0	0	0	0.000
160	10	295,882	1,479,409	1.479
170	20	874,062	7,329,130	7.329
180	30	2,010,808	21,753,482	21.753
190	40	3,789,677	50,755,907	50.756
200	50	5,500,020	97,204,390	97.204
210	60	7,693,940	163,174,191	163.174
220	70	9,828,056	250,784,174	250.784
230	80	11,964,812	359,748,513	359.749
240	90	14,386,213	491,503,637	491.504
250	100	17,107,778	648,973,593	648.974

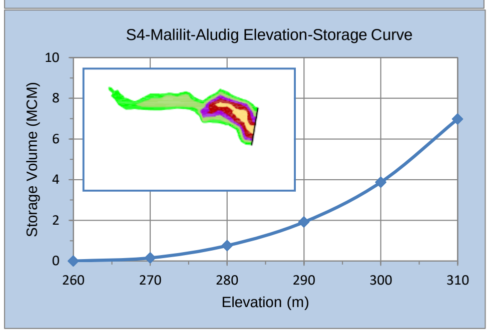


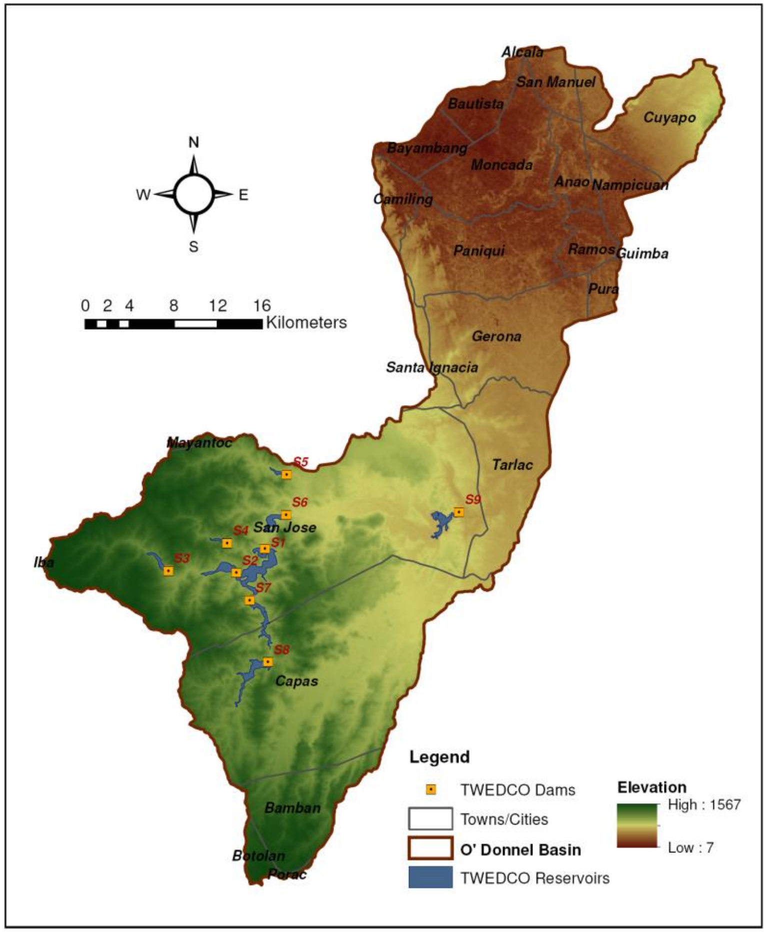
Proposed Balog-Balog Multiple Dam System (9 reservoirs)

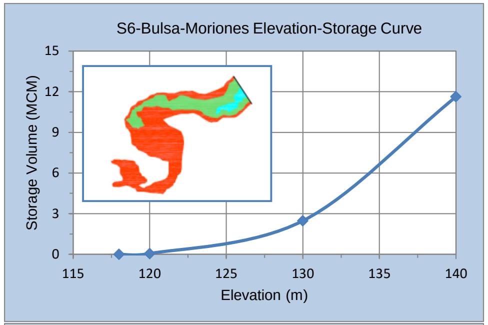


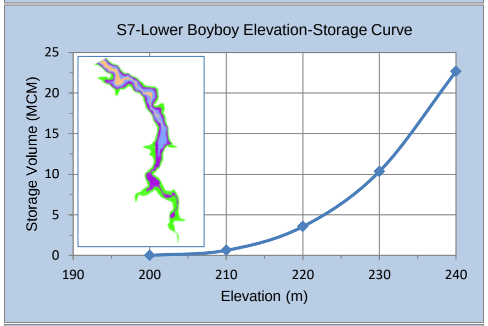


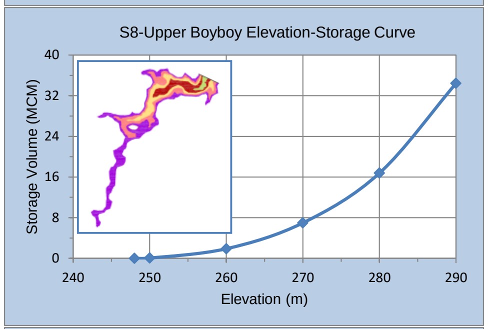


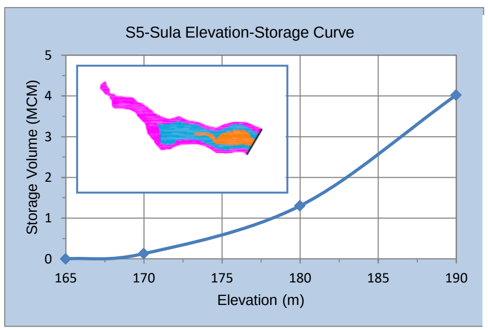


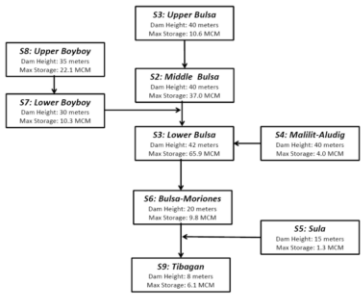


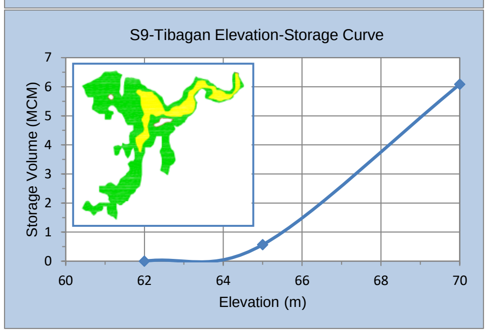






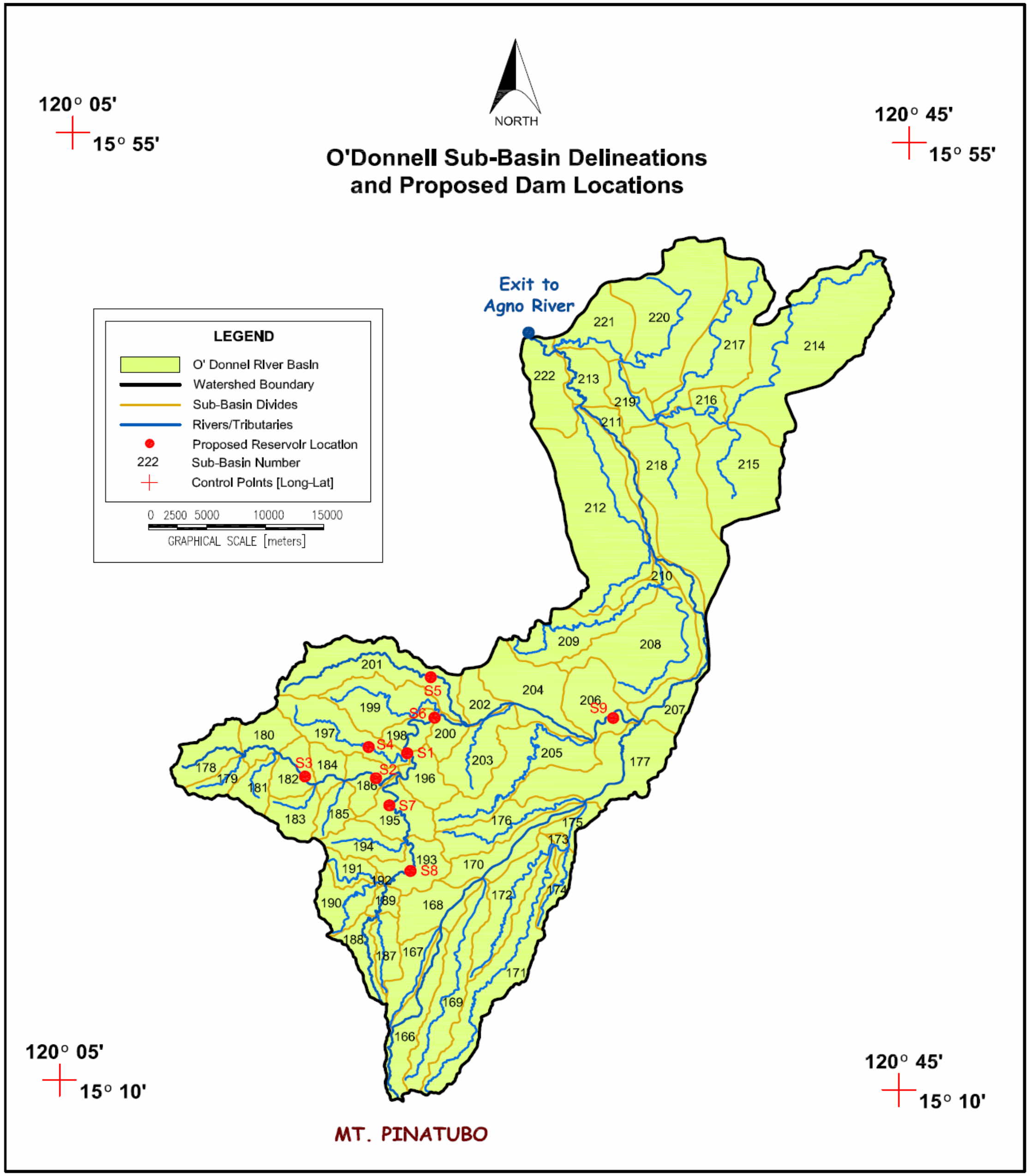




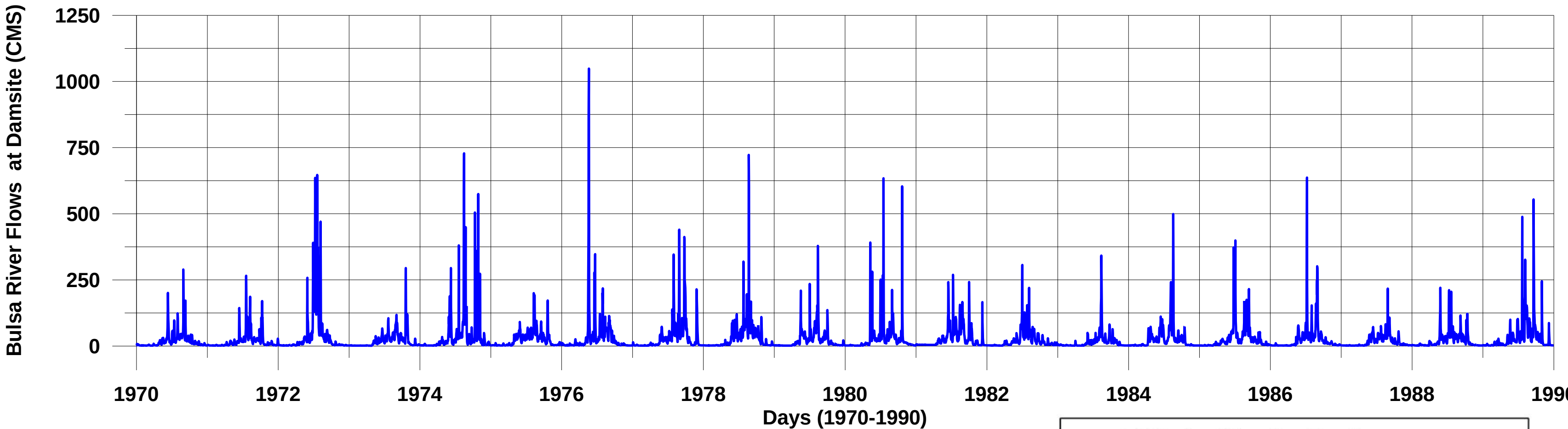


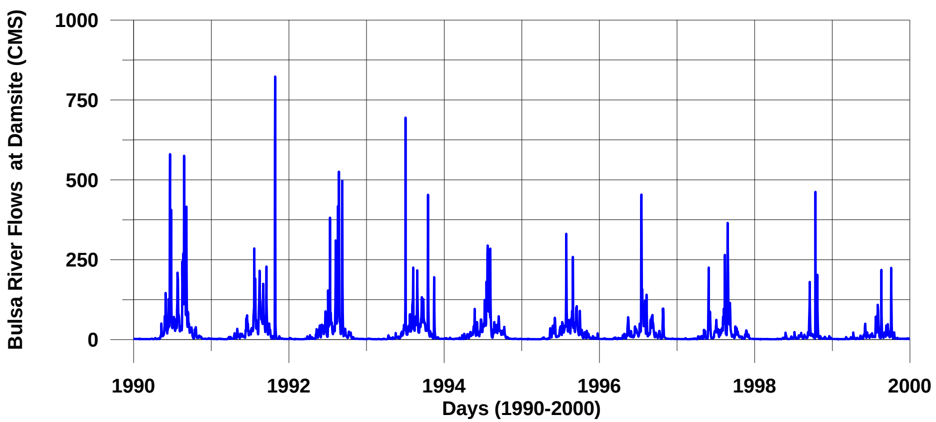
Comparison of Balog-Balog Single Dam Project and Multiple Dam System for the following items:

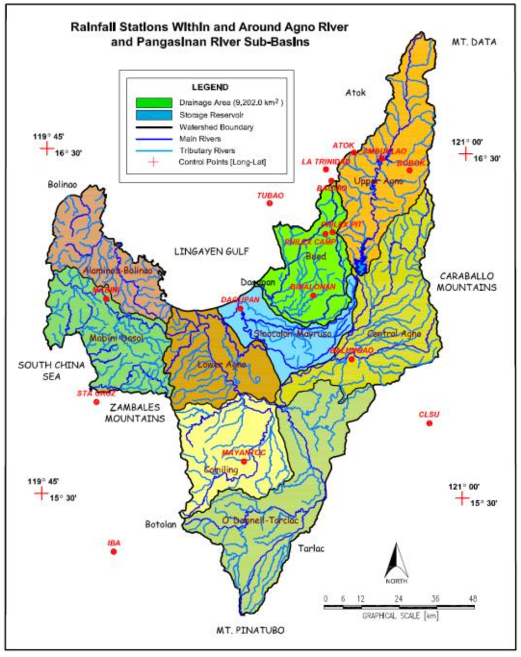
- Reservoir life due to sediment deposition
- Reliability of irrigation water delivery
- Reliability of hydropower generation
- Dam backwater upstream inundation
- Flood control benefits to downstream



Bulsa River Daily Flows (inflows to Balog-Balog reservoir): Reconstructed from watershed model using historical rainfall data from 1950 to 2000 which is assumed to be an equally likely realization in the future. (Only 1970-2000 flows are displayed.)







Reservoir Life Computations due to Sedimentation:

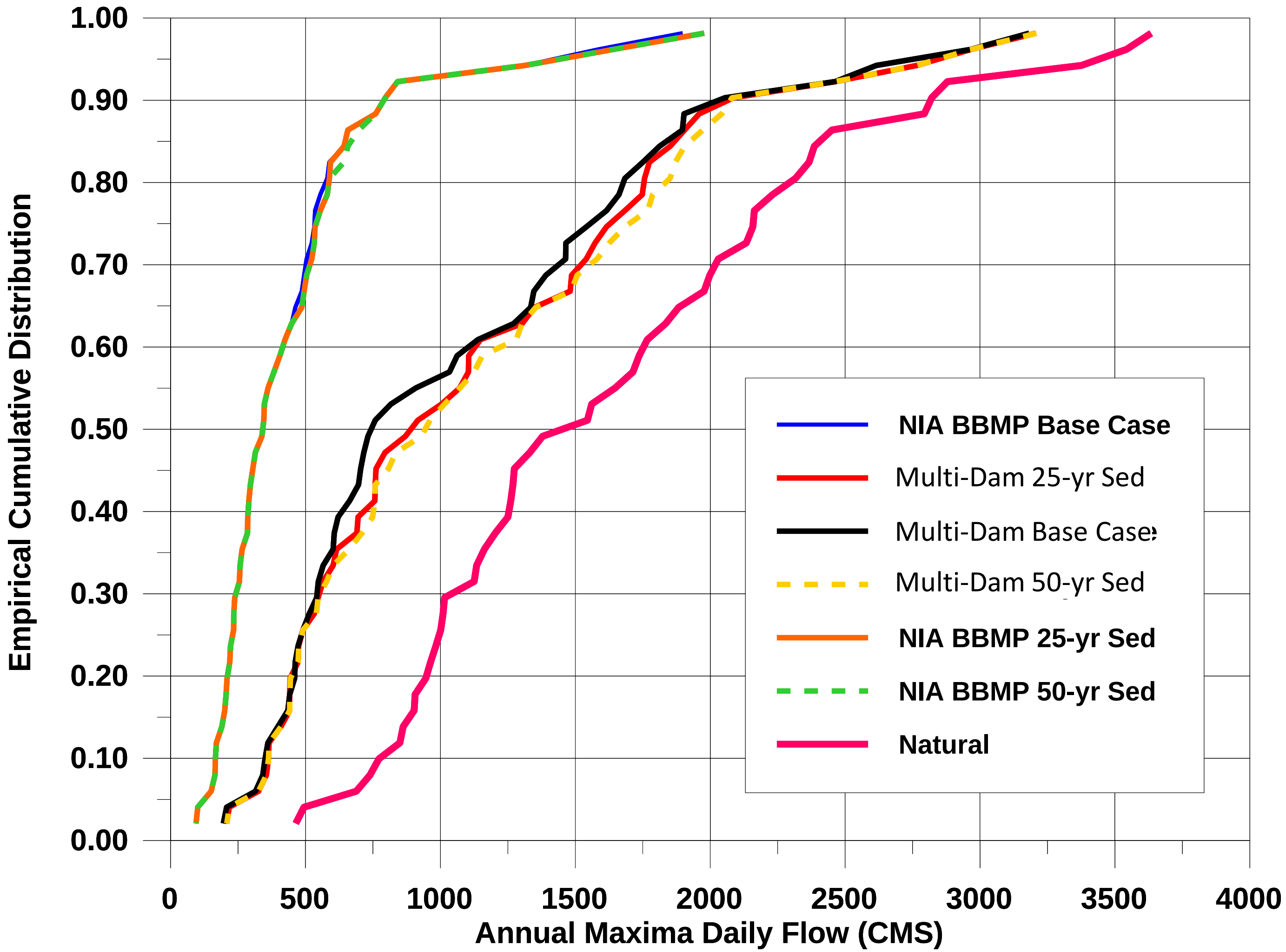
Sediment inflow used is 3500 m^3/year/km^2

		Drainage Area (km^2)	Annual Sediment Inflows (MCM)	Starting Storage (MCM)	Half-Filled Storage (MCM)	Year to Half-Filled Reservoir	Years to Fully-Filled Reservoir
BBMP Single, High Dam		289.31	1.013	648.97	324.49	321	641
BBMDS Dams	S1	36.43	0.128	93.09	46.54	366	731
	S2	48.74	0.171	46.10	23.05	136	271
	S3	67.34	0.236	15.77	7.89	34	67
	S4	24.65	0.086	6.98	3.49	41	81
	S5	41.62	0.146	4.02	2.01	14	28
	S6	10.36	0.036	11.63	5.81	161	321
	S7	42.91	0.150	22.67	11.33	76	151
	S8	69.23	0.242	34.42	17.21	72	143
	S9	182.27	0.638	6.08	3.04	5	10

Watershed/Reservoir	Drainage Area (km^2)		Sediment m^3/year/km^2	
Angat	568.0		5281.0	NHRC 2014
Binga	390.0		3695.0	NHRC 2007
Kaliwa	372.0		3225.0	NHRC 2013
Balog-Balog	283.0		2600.0	JICA 1988
San Roque	365.0		13307.2	NHRC 2003
		Ave (1st 3)	4067.0	
		Ave (4 Res)	3700.3	

Flood Frequency of Uncontrolled Flows at S9 Location: Balog-Balog Single Dam (BBMP) versus Multiple Dam system

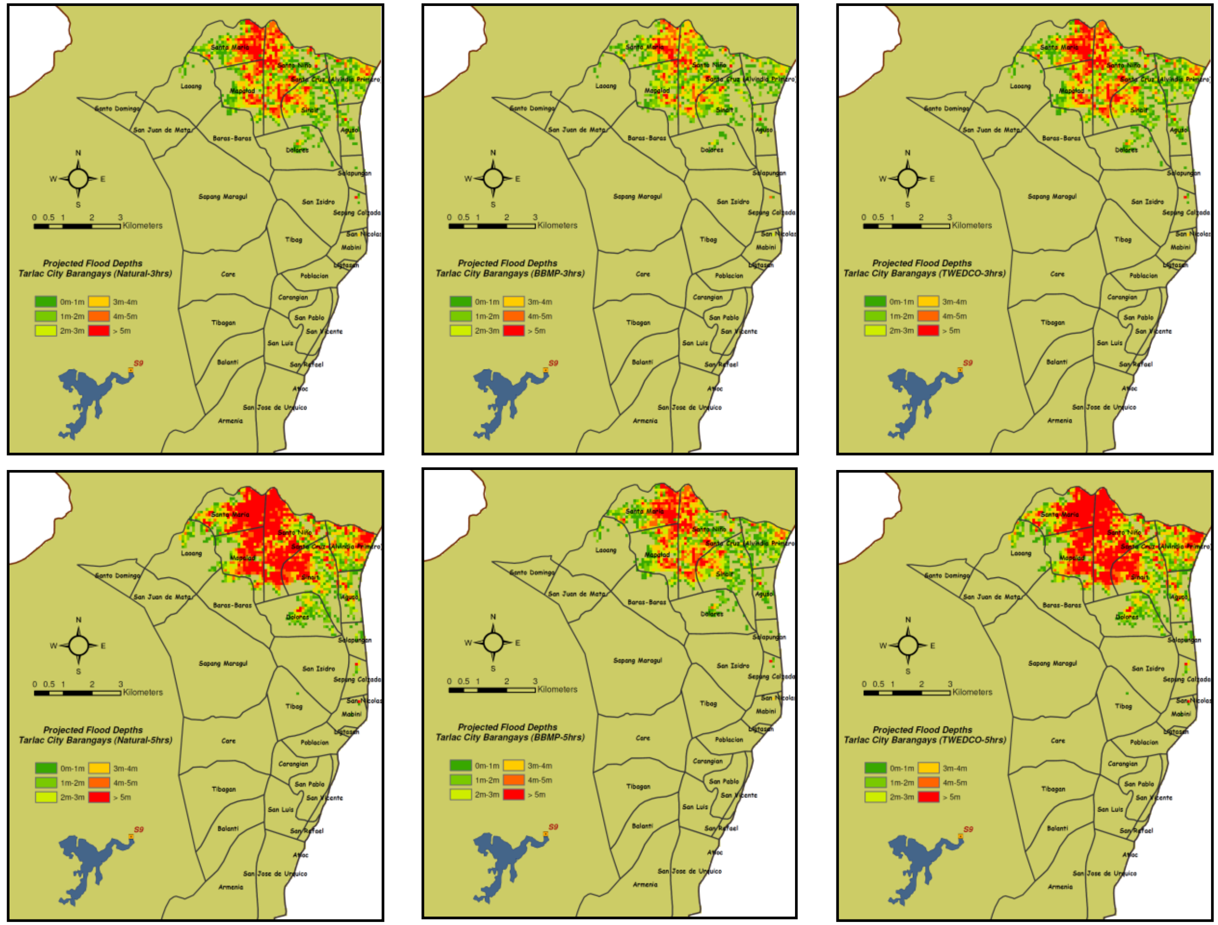
Clearly the BBMP has lower flood magnitudes compared to those of multiple dam scheme.



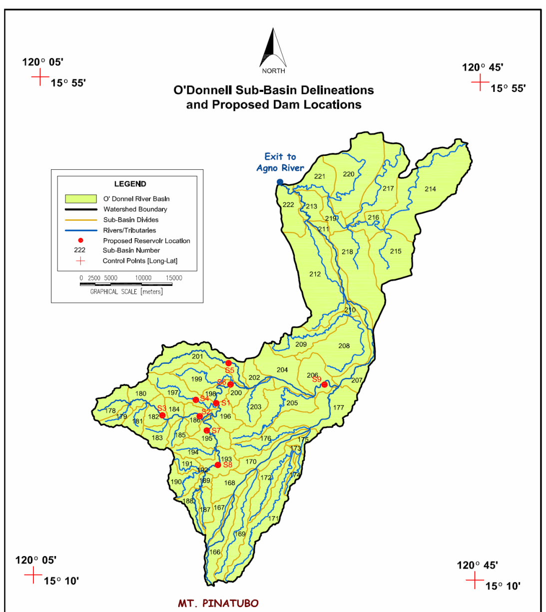
Flood Control Benefits to Downstream Cities

Flood inundated areas with sustained flows of 3 hours.

Flood inundated areas with sustained flows of 5 hours.



(a) without a reservoir (b) with BBMP single dam (c) with multiple dams



Scenario	Discharge (m^3/s)	Time Sustained (hr)	Total Flood Volume (m^3)	Total Flooded Area (ha)	Flood Water Level (m)	Average Flood Depth (m)
Natural-3Hrs	3650	3	39.420	120.265	39.947	3.278
BBMP-3Hrs	1980	3	21.384	96.073	38.308	2.226
MultiDam-3Hrs	3200	3	34.560	120.265	39.543	2.874
Natural-5Hrs	3650	5	65.700	157.934	41.735	4.160
BBMP-5Hrs	1980	5	35.640	120.265	39.633	2.963
MultiDam-5Hrs	3200	5	57.600	157.934	41.222	3.647

Estimates of benefit/cost (B/C) ratio, net present value (NPV) and economic rate of return (EIRR) for BBMP (single, high dam) and BBMDS (multiple dam) for base case and after 25 years & after 50 years with sedimentation. (Irrigation benefits for rice, sugarcane, corn, potato, eggplant, tomato, string beans, ampalaya, etc. but excludes hydropower)

Indicator	Base Case		Base Case plus higher investment & 20% less irrigation benefits		Case with 25 years reservoir sedimentation		Case with 50 years reservoir sedimentation	
	BBMP	BBMDS	BBMP	BBMDS	BBMP	BBMDS	BBMP	BBMDS
B/C Ratio	2.77	1.67	1.84	1.12	2.73	1.19	2.71	1.16
NPV @ 15% (million pesos)	6,128	2,972	3,514	612	5,991	819	5,921	703
EIRR	27	20	21	16	27	17	27	16

Observation: **Results indicate higher B/C ratios, NPV and IRR for all BBMP single dam cases excluding hydropower component**

On Sustainable Planning and Management of Multi-Purpose Reservoir Systems

- **Reservoirs and dam projects in the Philippines and even other parts of the world are rarely or not at all planned in the timeframes of sustainable development which is "not only for the current generation, but future generations to come".**

- **Specifically, most of these reservoir and dam projects are justified based on an economic life (i.e., period of B/C and IRR computations) of 50 years and at most 70 years thus covering one future generation.**

- **A major reason for this practice is that reservoirs by nature trap sediments from upstream watersheds so reservoirs are assumed to have finite lives of at most 70 years unless proper reservoir sedimentation management strategies are in place.**

- **Another reason may be simply because it is much more difficult to justify projects as well as for governments including private investors to appreciate economic planning horizons of 150 to 200 years.**

- **A major issue with reservoirs is that it could 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 river ecology and ecological integrity.**

- **The river downstream will starve from seasonal supply of sediments that is responsible for maintaining stable channels such as riffle-pool sequence that prevents too much erosion or sedimentation in portions of the river downstream thus creating flooding or bank erosion problems and even river migration to settlement areas.**

- **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.**

- **Thus, there is need to develop and implement a framework to conduct sustainable water resources development of large-scale water resources systems that involve large-scale reservoirs and dams including large, regulated river works so that the planning horizon is over 150 to 200 years.**

Conclusions

- **Sustainable water resources development is a complex problem and definitely non-deterministic, dynamic and uncertain due ecosystem, land use & 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 & political factors and must cover infrastructural, institutional, economic & social 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.**

Last Slide!