Appendix C Sediment load partitioning of the Agno River and changes in the shoreline position

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Introduction

The Agno River, the fifth largest river in the Philippines, is the largest river in terms of drainage area and discharge that empty into Lingayen Gulf. Its water discharge accounts for almost 70% of the total fresh water input into the gulf (Table C1). The Agno River originates from the slopes of Mt. Data in the Cordillera Mountains at an elevation of 2090 m, where it drains Cretaceous to Paleocene igneous basement rocks, and marine siliciclastic and carbonate rocks. Several mining districts are located within these upper reaches of the Agno River. Two major hydroelectric dams, Binga and Ambuklao (Figure C1), have been in operation since 1950 and 1956 respectively, and a third, the San Roque Dam, is presently being constructed. As the river descends following a southerly course, it exhibits a braided channel pattern. It then transforms into a southwest-directed meandering river as it crosses the Central Luzon Alluvial Plain. From the confluence with the Tarlac River emanating from the south, the Agno River then veers northward while draining the eastern flanks of the ophiolite Zambales Mountain Range. Historically, this last reach exhibited meandering channel patterns, but it has been transformed into single and relatively straight channels due to river control works since the early 1970's.

Our primary aim in this report is to come up with initial estimates of the partitioning into suspended, bed, and dissolved components of the Agno River's sediment load as it reaches the coast. We used the changes in shoreline position to estimate the bed load delivered to the coast. Secondary data were used in estimating the likely magnitudes of suspended and dissolved loads.

Table C1: Major river systems draining into Lingayen Gulf.

RIVER SYSTEM	Drainage Area (km^2)	Discharge (10^6 m^3y^{-1})	Length (km)
Agno	5952 [a]	6664 [a]	275 [c]
Dagupan (Panto)	1115 [c]	1002 [a]	75 [c]
Bued-Patalan	630	388 [a]	61 [c]
Aringay	397	929 [b]	75
Bauang	516	674 [b]	92
Inerangan-Coliat-Barcadero-Garita	200 [a]	224 [a]	

[a] NWRC Phil. (1976) in *Philippine Water Resources (Ecological Profile of Pangasinan)* MHS/NEPC & NACIAD
[b] Bauang-Amburayan River Basin (Area Profile)
[c] Draft Final Report for Study of Agno River Basin Flood Control (JICA, 1991).

Data and Methods

Shoreline and Volumetric Changes

Estimation of the Agno River's bed load input into Lingayen Gulf is based on the changes of shoreline position and offshore profile. The oldest shoreline data is from a 1940 reconnaissance survey published in a 1944 topographic map. Another topographic map published in 1955 derived its coastal outline from a set of aerial photographs taken in 1950. The latest topographic map has data from 1977. The 1989 and 1991 shoreline data were taken from aerial photographs and a Synthetic Aperture Radar image, respectively. These shoreline data sets were enlarged or reduced to a scale of 1:50,000 and were either traced manually or with the aid of an Aero Sketchmaster into the 1977 topographic map which served as the base map. Data for the offshore region was derived from the series of 1902-1903 hydrographic surveys contained in NAMRIA Bathymetric Chart #4209 (1980). We acquired the 1997 to 1998 bathymetric data by making spot water depth measurements with a depth meter operating at a frequency of 455 Khz. Positions were established using a hand held GPS unit.

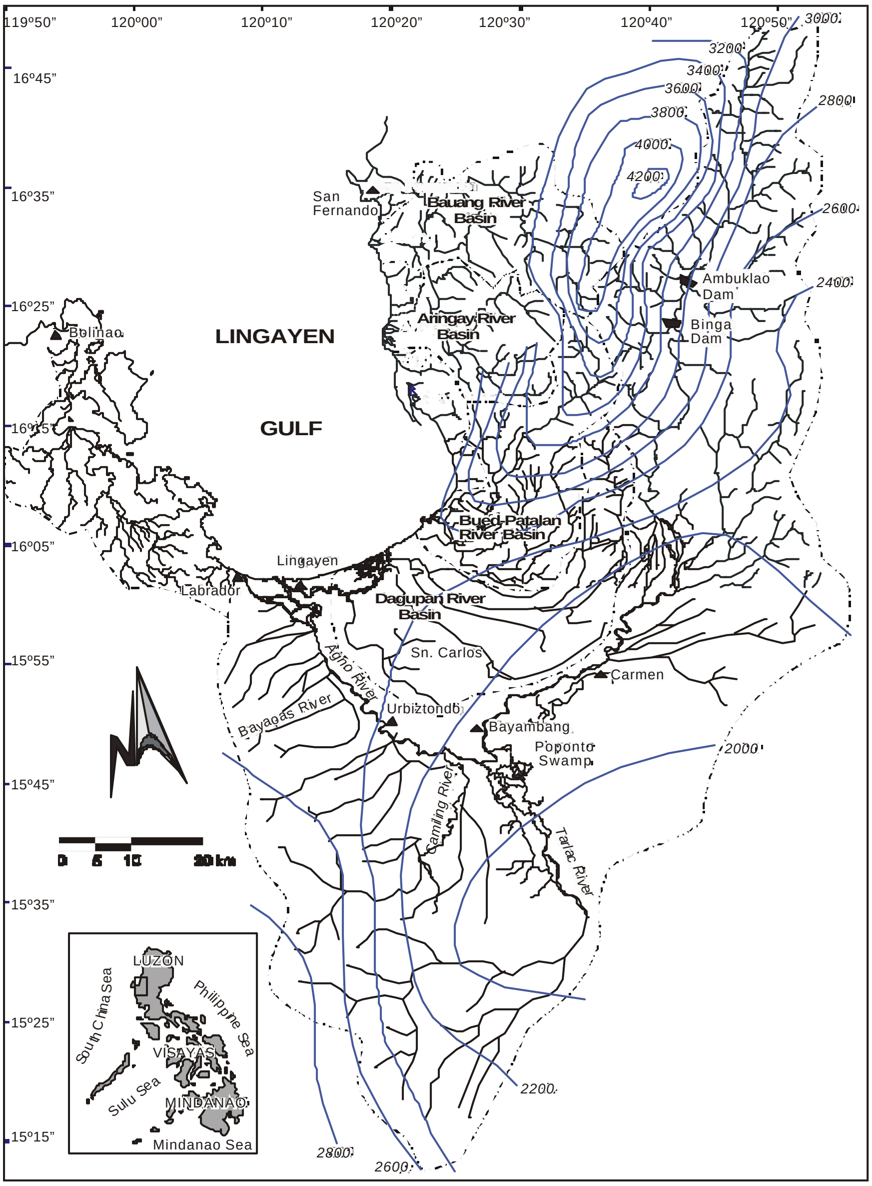

Figure C1. Watershed map of Lingayen Gulf showing the different river basins and isohyetal lines in intervals of 200 mm. From David et al. (1997); JICA (1991)

To facilitate the computation of volume, the shorelines and isobaths defining the present deltaic and non-deltaic shorefaces were digitized. The total area that was eroded or prograded along the Agno Labrador and Agno Lingayen deltas were then computed using AutoCad. The x,y,z coordinate of data points were also extracted using a written Visual Basic programming tool in preparation for input in a generic mapping software. From the grid data, the volume was calculated using SURFER. The closure depth, derived from the lower limit of the predominance (50%) of sand in the surface sediment and from the average depth of occurrence of sand as reflected in the borehole data from adjacent coastal plains, was set at 15 m. This depth was set to delimit the offshore transport of the bedload. Final outputs are 1950 and 1991 surface maps and volumetric change of Agno-Lingayen Delta.

We assumed that the sediment eroded from the adjacent Agno-Labrador delta to the east was transported and subsequently accreted, 100%, to the western flank of the Agno Lingayen delta. This is based on the predominance of eastward longshore currents along the coastline west of the Agno Lingayen delta. An additional assumption is that no sediment is lost to or gained from the coastal area east of the delta.

Estimation of Suspended and Dissolved Sediment Discharge

To estimate the magnitudes of suspended and dissolved loads of the Agno River, secondary data generated by the Bureau of Soils and EIA reports were used. Several stations were reoccupied during the above studies (Figure C1). We wanted to use a station downstream but, except for Bocboc in San Carlos City where only one measurement of SS was made, the rest of the stations were situated right at the mouths of the Agno-Lingayen and Agno-Labrador channels. We did not include these stations because of the influence of seawater in the measured concentrations. The only other station that is close to the coast where several measurements were done is in Bayambang, Pangasinan, 9 kilometers upstream of the Agno–Tarlac River confluence or 54 km from the river mouth. We multiplied the measured concentrations with the mean annual discharge of $9x10^9$ m^3/yr measured at Urbiztondo for the period 1959–1970. Note that this yearly mean is 34% higher than the yearly average reported by NWRC (1976) and which is used in Table C1. Water discharge values at the site and time of measurement are unavailable.

Results and Discussion

Shoreline Changes

From 1950 to 1964, the shoreline within the Agno–Lingayen River mouth prograded by a maximum of 300 m (Figure C2; Table C2A). This progradation also marks the shift of this river mouth from a linear shoreline to a deltaic shoreline. The prograded area is $1.5x10^6$ m^2. This area of progradation together with the change of shoreline character, from linear to deltaic, would require sediment input amounting to $69.2x10^6$ m^3. Erosion ensued from 1964 to 1977. Progradation resumed from 1977 to 1991. The maximum net progradation from 1950 to 1991 was 1050 m. The net prograded area is $3.6x10^6$ m^2 which would require a total sediment input of $179.1x10^6$ m^3.

The Agno-Labrador delta, in the 51 years from 1940 to 1991, underwent continuous shoreline retreat of as much as 910 m (Figure C2; Table C2B). This caused erosion of $1.9x10^6$ m^2 in delta plain area. To compensate for this, a corresponding amount of $1.61x10^6$ m^3 was taken out from this delta. The most drastic event occurred during the first 10 years (1940 to 1950) when the shoreline retreated by as much as 333 m, eroding $0.8x10^6$ m^2 of the former delta plain and causing removal of $23.5x10^6$ m^3 of materials.

However, within the next 14 years (1950–1964), the shoreline retreated by only 139 m accompanied by a decrease of only $0.2x10^6$ m^2 and $8.4x10^6$ m^3 in delta area and volume, respectively. Farther reduction in the seaward extent of the delta occurred from 1964 to 1977 when the shoreline moved 222 m landward, removing $0.4x10^6$ m^2 of land surface which correspond to a decrease of $6.6x10^6$ m^2 in the delta volume. In 1989, the shoreline again receded by 277 m from its position in 1977. Likewise, the area decreased by $0.5x10^6$ m^2 and the volume by $1.1x10^6$ m^3. From 1989 to 1991, there was no detectable change in the shoreline position.

Bed Load Calculated from Shoreline Changes

From 1950 to 1991, the volume of net progradation, which includes the eroded volume during the period 1964–1977, in the Agno Lingayen Delta is $179.1x10^6$ m^3 (Table C2A).

Table C2A: Changes in the Agno-Lingayen (Limahong Channel) Delta

Year interval	Period (no. of years)	Maximum shoreline advance (+) retreat (-) (m)	Rate of advance (+) or retreat (-) (m/year)	Net change in area: increase (+) or decrease (-) (x 10^6 m^2)	Volume Change (x 10^6 m^3)
1950 – 1964	14	+ 590	42	1.5	69.2
1964 – 1977	13	- 410	32	- 0.6	-45.2
1977 – 1989	12	+ 820	68	2.6	55.0
1989 - 1991	2	+ 60	30	0.1	9.7
Total		**1060**		**3.6**	***179.1**

- In this total, we treated the 1964-1977 volume change as a positive change. What had eroded was accounted for as sediment input.

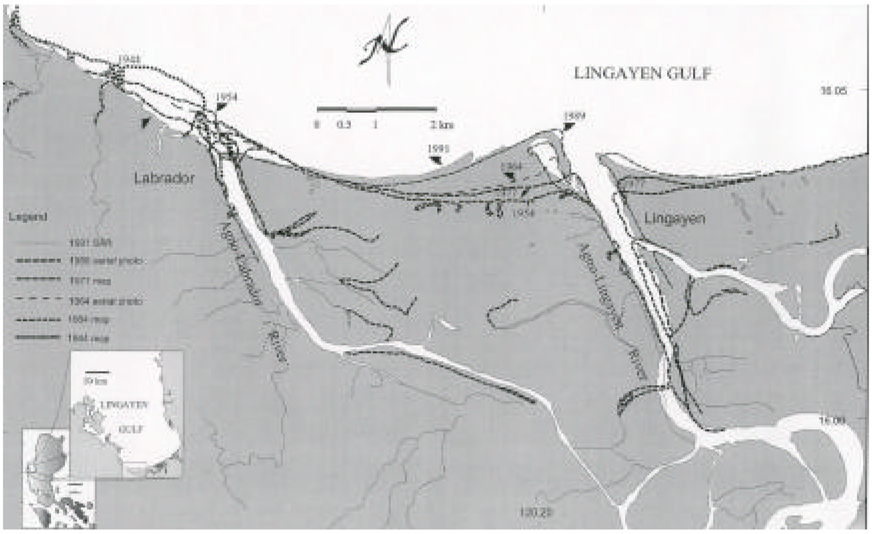

Figure C2. Shoreline change map of the Agno-Lingayen and Agno-Labrador deltas.
Sources: 1944, 1954 maps were published by the US Army Corps of Engineers; 1964 data from SRMP ERA (1997); 1977 topographic map and 1991 SAR image from the Philippines National Mapping and Resoirce Information Authority (NAMIRA).

Table C2B: Changes in the Agno-Labrador delta.

Year interval	Period (no. of years)	Maximum shoreline advance (+) retreat (-) (m)	Rate of advance (+) or retreat (-) (m/year)	Net change in area: increase (+) or decrease (-) ($x10^6$ m^2)	Volume Change (x 10^6 m^3)
1940 - 1950	10	-333	-33.3	- 0.8	- 23.5
1950 - 1964	14	-139	-9.93	- 0.2	- 8.4
1964 - 1977	13	-222	-17.1	- 0.4	- 6.6
1977 - 1989	12	-277	-23.1	- 0.5	- 1.1
1989 - 1991	2	0	0	0	0
Total		**971**		**1.9**	**20.6**

During the same period, the net eroded volume in Agno Labrador is $16.1x10^6$ m^3. Assuming that all of the sediment eroded along Agno Labrador was transported to Agno Lingayen, the required sediment input would be $163x10^6$ m^3 within the 41-year period, or equivalent to a yearly input of $5.6x10^6$ using a bulk density of 1.4 tons/m^3.

Not all of these would be bed load. The closure depth of 15 m, as defined earlier is the depth where the sand concentration of the surface sediment drops to below 50%. If we assume that only half of the prograded volume is bed load, fine sand and coarser, then the required input would be approximately $2.8x10^6$ tons/year.

Suspended and Dissolved Loads Based on Secondary Field Measurements
Table C3 shows the magnitudes of measured concentrations of suspended and (SS) dissolved (DS) loads of Agno River at Bayambang. The tabulation shows the possible range of suspended and dissolved loads delivered to Lingayen Gulf. The suspended load ranges from a low $1.3x10^6$ tons/yr during dry period, to a high of $13.3x10^6$ tons/yr during the middle of the rainy season. The mean is $4.1x10^6$ tons/yr. For the dissolved load, the low value is $1.4x10^6$ tons/yr during the rainy season while the high value is $4x10^6$ tons/yr., also during the rainy season. The mean is $2.1x10^6$ tons/yr. Overall, the measurements indicate that the likely magnitude of suspended and dissolved loads delivered to Lingayen Gulf is in the order of 10^6 tons/yr. and that the dissolved load could be half of the suspended load. However, at the Bayambang station, the input from the western sub-basins are still unaccounted for. Thus, it is more likely that the actual amounts of suspended and dissolved loads delivered to the coast are higher.

Table C3. Suspended and dissolved loads from secondary data.

Station	SS (mg/l)	DS (mg/l)	SS (x 10^6 tons/yr)	DS (x 10^6 tons/yr)
Bureau of Soils (Aug.75- Nov.76)				
Wet (Bayambang)	514	184*	4.6	1.7
Dry (Bayambang)	140	225*	1.3	2.0
Bureau of Soils (June 1981)				
Bayambang (Poblacion)	480		4.3	
Bayambang (Wawa)	298		2.7	
Bocboc (San Carlos City)	235		2.1	
NPCC (Bayambang)	300	200*	2.7	1.8
1984 SRMP EIA				
Aug	240	440	2.2	4.0
Sept	1480	160	13.3	1.4
Oct	620	200	5.6	1.8
Dec.	360	200	3.2	1.8
Feb.	340	290	3.1	2.6
*derived from (total solids - suspended sediments)		**Mean**	**4.1**	**2.1**

Sediment Partitioning

JICA (1991) estimates that the total amount of sediment delivered by the Agno River to the coast is 6.3×10^6 m^3/yr. Using 1.6 tons/m^3 as bulk density of watershed materials, the above sediment delivery would be equal to 10.1×10^6 tons/yr. The progradation of the Agno-Lingayen delta would account for at least 28% of the above. If some of the bed load material is from the eastern flanks of Agno-Lingayen delta, this percentage may go lower. Based on the secondary field measurements the suspended load may account for 41% while the dissolved load may account for 21%.

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