Worsening Floods around Northern Manila Bay, Philippines: Research-Based Analysis from Physical and Social Science Perspectives

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Paradoxically, flooding continues to worsen on the heavily populated and highly cultivated deltaic coastal plains around Manila Bay, even during the current period of reduced rainfall. In Pampanga Province, volcanic sediments from the 1991 Pinatubo eruption have clearly enhanced flooding by clogging stream channels, but long before 1991 this area was already experiencing increasing flood frequency, magnitude and duration. Furthermore, the adjacent areas of Bulacan Province and the Metro Manila's coastal KAMANAVA suburbs received little Pinatubo debris, but are also increasingly flood-prone.

Urbanization and deforestation are important causes of the worsening floods but, in the long-term, rising local sea level is the primary factor. This is not the 2 mm/y rise induced by global warming, for regional subsidence is much more rapid. Deltaic muds naturally "autocompact" after deposition: under their own accumulating weight, water is squeezed out, they thin, and the surface subsides slowly. Dewatering and subsidence are greatly accelerated by heavy extraction of groundwater for fishponds, farms, and the rapidly growing population. Annual subsidence of several centimeters measured at many Pampanga well-sites has been independently confirmed by recent geodetic resurveys. Social research refines and enriches our physical dataset by tapping and quantifying the regional population's long-term experience of both storm and tidal flooding. Sociological data regarding floods and tides from 53 sites indicate regional subsidence of 3-8 cm/y since 1991.

Hidden underground and slow, subsidence escapes attention and allows gradual, short-time fixes for worsening floods. Perhaps only a worst-case deluge from simultaneous high tides, storm surges and rains will educate the people and bring about proper mitigation. Government efforts favor short-term political contingency over efficacy. Local politicians build wells to court votes; most national leaders are unaware of subsidence, and foreign engineering consultants ignore, deny or minimize the importance of subsidence. Expensive, ineffective dredging and diking projects, funded with foreign loans that stipulate the use of foreign expertise and ignore Filipino scientists, are vulnerable to corruption. People whose only assets are ancestral homes and lots are reluctant to recognize that their own wells are a major cause of flooding. They demand engineering solutions, but make them even more ineffectual by refusing rights-of-way. Flooding can be ameliorated in the short-term by restoring channel widths and modifying aquaculture. Reforestation would increase infiltration and decrease erosion and siltation. Rapid subsidence will persist if groundwater use is not considerably augmented by surface sources. Even so, flooding from both natural compaction and global sea level rise will continue. Adaptive solutions must be implemented, either ad hoc or by enlightened land-use.

Introduction

Manila Bay is bordered to the north and northeast by the deltaic plains of many rivers that drain Bataan, Pampanga, Bulacan, and the northern Manila suburban area called KAMANAVA, an acronym derived from the names of the Kaloocan, Malabon, Navotas and Valenzuela (Fig. 1). The region's highly developed agri- and aquaculture make it both a "rice and sugar basket" and "fish basket." Except for Metro Manila, which also relies heavily on surface sources, artesian springs and groundwater from shallow and deep wells are the main source of fresh water for domestic, recreational and industrial uses, fishponds, and, to a lesser extent, rice fields.

Worsening floods in this region have been drawing much attention over the past decade. Since the 1991 Pinatubo eruption, flooding has been enhanced in southwestern Pampanga, where channels have been choked with great amounts of eruption debris brought down by lahars (flowing slurries of volcanic debris) and more dilute runoff. Long before 1991, however, the area was already notoriously flood-prone and was already experiencing increasing flood frequency, magnitude and duration. Furthermore, coastal Bataan, Bulacan and KAMANAVA, which received virtually no Pinatubo sediment, are also suffering from aggravated flooding. Clearly, factors independent of Pinatubo are more important. The more widely cited of these include the various effects of unchecked urbanization: decreased infiltration and increased runoff due to expanding pavement; encroachment of channels by informal settlers and fishponds (Nippon Koei 2001); and choking of streams by improper garbage disposal (Orejas 2000). Upland deforestation also contributes, by increasing runoff, slope erosion, and channel filling.

Only recently (Tacio 1999a, 1999b) have the Philippine public and decision makers begun to recognize that global warming is causing worldwide sea level rise to rise about 2mm/y (Turekian 1996, Mimura 1998, Pirazzoli 1998, Mimura and Harasawa 2000). They have yet to accept that northern Manila Bay is subsiding more than ten times faster, like deltaic areas are all over the world where water is being pumped too quickly out of the ground. Planned and proposed flood-mitigation measures, which include multi-billion-peso dredging and diking projects, ignore or minimize the subsidence phenomenon, and thus could well be futile.

Our study of the role of the different factors that contribute to worsening floods and subsidence began in the Pampanga portion of the coastal plain in 1998, funded by the Center for Integrative and Developmental Studies of the University of the Philippines (Siringan and Rodolfo 2001:1-5). Our continuing research on the entire bayhead region integrates physical and social approaches and has been funded since 2001 by the Department of Agriculture (Siringan and Rodolfo 2002a). The humanitarian organization Oxfam Great Britain—Philippines has provided funding for supplementary research and for disseminating our findings to local governments and non-governmental organizations (Siringan and Rodolfo 2002b). This report summarizes our physical findings and our social data. We examine trends in population growth insofar as they might reflect how the communities on the plains might be responding to enhanced flooding. Lastly, we discuss the physical and anthropogenic factors that worsen the flooding, propose avenues for continuing research, and suggest several measures that could mitigate the problem.

Geology, geography, and climate

The flood-prone coastal lowlands constitute almost 3,000 km^2 of the southern central valley of Luzon Island, from the Pampanga communities of Angeles City and Arayat town in the north, to the coast that stretches eastward and southward from northeastern Bataan to KAMANAVA (Fig. 1). To the west, the area is bounded by volcanic rocks of the eastern Zambales Mountains, including Mount Pinatubo and its two dormant sisters, Mts. Natib and Mariveles, which form the Bataan peninsula. To the east, the plains abut the Sierra Madre Mountains. Geophysical data and exploratory boreholes show that deltaic and shallow-marine sediments and sedimentary rocks more than 7 km thick have accumulated over the last 24 million years (Bureau of Energy Development 1986).

The coastal plains are so flat and close to sea level that the 1 meter elevation extends 10-20 km inland, and so even small rises in relative sea level translate to large encroachments of the sea. Marshy and cut by numerous tidal inlets, the more seaward flats are almost entirely converted to fishponds that continue to encroach northward and occupy larger portions of channels. Areas still above tidal influence are planted to two annual rice crops. Paddies are converted to fishponds with the progress of saltwater intrusion, which already extends more than 20 km inland in some places.

Manila Bay tides are predominantly diurnal, with a vertical range of 1.25 meters. The highest spring tide of record, 1.93 meters, was set on July 4, 2000 (Nippon Koie 2001), during a period of sustained monsoonal winds (unpublished NAMRIA records). By an unfortunate combination of coastal configuration and seasonal winds, the same southerly and westerly airflows that deliver the annual rains also pile up seawater at the western coasts, temporarily raising sea level and hindering storm runoff from draining seaward. Empirical data regarding the extent of wave setup and storm surge are very few – a great lack; however, surge can easily raise tide heights by 80 percent (Siringan and Ringor 1998), and twice, during typhoons in 1972 and 1976, waves superimposed on storm surge lifted and drove sea-going cargo vessels aground on the breakwaters of Manila's Roxas Boulevard (Brand et al. 1979).

Rainfall is distinctly seasonal, about 70 percent arriving during the rainiest months of June through September, when southwesterly monsoonal winds bring in maritime

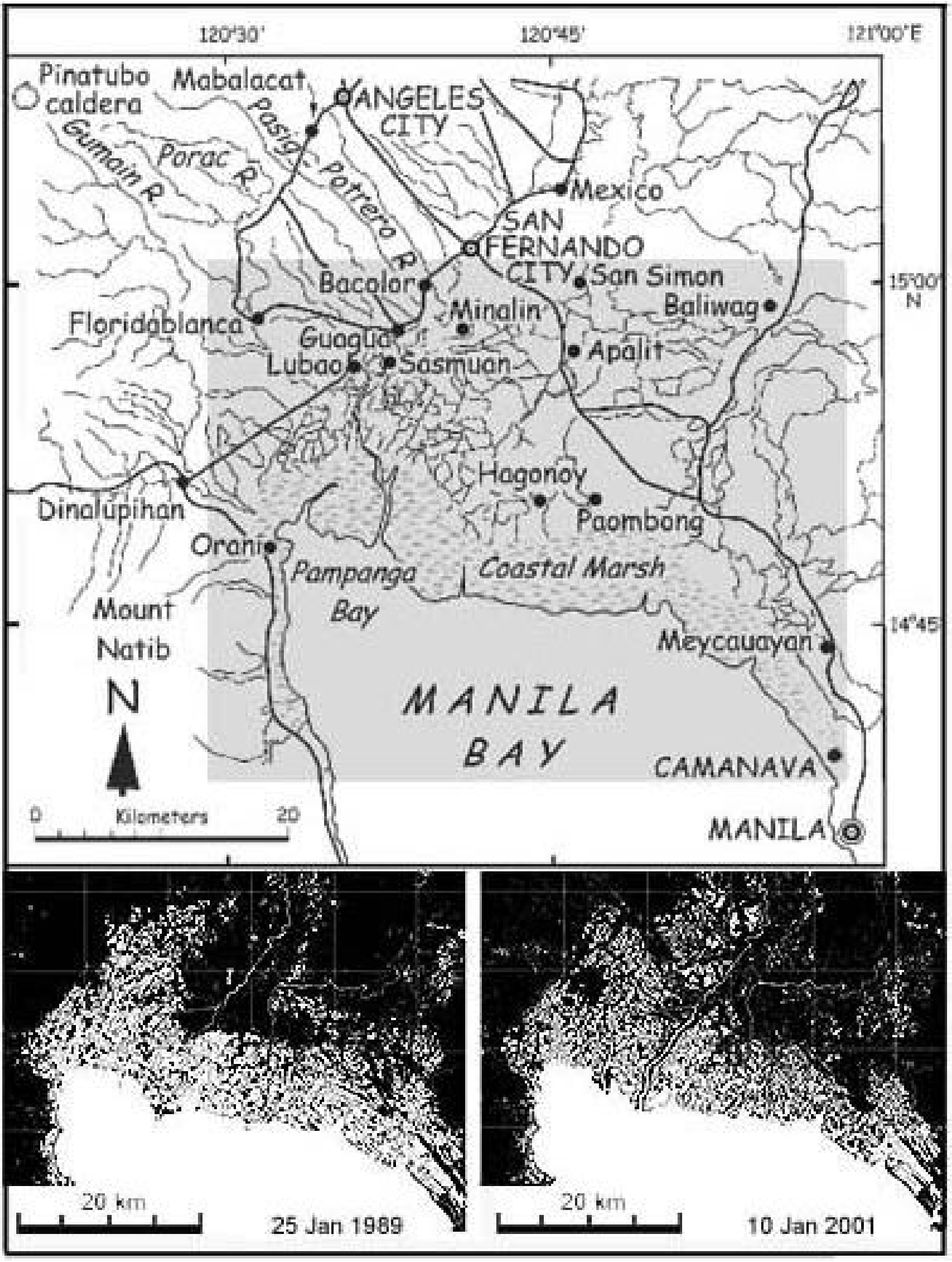

Figure 1. Location Map of the Area Around Northern Manila Bay

equatorial air from the South China Sea. The most intense precipitation is brought directly by three or four annual typhoons, and by southwesterly airflow enhanced by more distal typhoons, about 17 of which enter Philippine space every year. Typhoons and typhoon-enhanced monsoonal flow is responsible for about half of all the rainfall (Umbal and Rodolfo 1996). Annual precipitation varies greatly in the region, depending upon whether or not an area lies in the lee of the Zambales Mountains and Bataan peninsula. Thus, San Fernando City receives only about 1,900 mm, whereas Manila receives more than twice as much, typically in excess of 4,000 mm (unpublished NAMRIA records).

It is a great pity that such an abundance of rain is so seasonal, and that surface reservoirs are too small to store enough water for the agriculture, fishponds, and domestic needs of the regional population, which must rely far too heavily on groundwater. Two serious consequences are rapid ground subsidence and enhanced storm and tidal floods, the central topics of this report.

North and northeastern Manila Bay receives approximately 1.2×10^{11} m^3 of water from the Pampanga and numerous other rivers. Even before the 1991 Pinatubo eruption, the greatest source of bay sediment, about 1.2×10^6 tonnes annually (JICA 1982) was Pinatubo and adjacent portions of the Zambales mountains, and yet, curiously, the receiving northwestern shoreline, instead of bulging seaward, forms the Pampanga Bay. Since 1991, this part of the shore has been receiving great quantities of volcanic sediment, but the nearshore bay floor has not shoaled appreciably since 1961 (Siringan and Ringor 1998). Clearly, sedimentation is being offset by local subsidence.

METHODS

Physical

Siringan and Rodolfo (in press) have described the physical aspects, methods and findings of our research in detail. A time-series analysis of selected bandwidths sensitive to the presence of water in satellite images (Balboa 2002) has revealed subtle but valuable documentation of how the distribution of waterlogged areas has evolved between 1989 and 2001. Using global positioning systems (GPS), we have gathered precise elevation data at 19 stations, which are expected to yield subsidence data when reoccupied in several years. Sediment cores from 32 stations as long as 10.2 meters are being analyzed for evidence of changing environment. Several regional lineaments defined by drastic contrasts in false-color satellite images are yet to be tested as possible faults using microseismic records and ground-truthing that will include ground-penetrating radar surveys.

Sociological

We augment our physical approaches with social research methods. Information is gathered from area residents in three ways: indepth interviews of key informants from each *barangay* (village), social surveys, and meetings and discussion fora at which we present and validate our analyses and findings, as well as elicit reactions and responses.

A key informant from each barangay provides community-level information such as locations of emerging water-wells, changes in land use, severity of flooding, and heights and extents of maximum tides. The 1991 Pinatubo eruption was such a dramatic event that it serves well as a historical benchmark with which to gauge changes in flood and maximal tide heights. Each informant is a longtime resident of the barangay with good recall of events, preferably a leader from government, civic, religious, or other nongovernment organizations.

Our survey questionnaires were initially designed, tested and used in Pampanga (Siringan et al. 2002: 58-59), and then modified and applied in Bulacan and KAMANAVA. These instruments were developed from a preliminary list of initial questions that was pretested in Sta. Rita, a barangay in Minalin municipality that is flooded for more than six months of the year. The results were used to refine the survey questionnaire and to develop a guide with which to interview key informants. That guide in turn was pre-tested in San Rafael Baruya, Lubao, Pampanga, which always is flooded by high tides, and in San Vicente, Bacolor, a barangay previously affected by floods and lahars.

The survey instrument solicits from individual households of selected barangays information regarding the following:

- Emerging well pipes as indicators of ground subsidence; saltwater intrusion; information on wells, including depth, when constructed and/or modified, who constructed them, and the sizes of the population they serve.
- Siltation of river channels
- Flooding histories of the areas, including their heights, durations, and recurrence intervals.
- Changes in inland tidal levels and surface saltwater incursion and attendant changes in vegetation especially along coastal towns.
- Agriculture and aquaculture histories of the areas.

Beginning in Pampanga, municipalities were selected to identify and map the spatial variations of the factors contributing to relative sea level change in the region. Of the 22 Pampanga municipalities, 11 were selected and classified according to: location in noncoastal areas less prone to flooding; flood-prone noncoastal areas; and coastal areas highly susceptible to flooding, these last two being assigned the highest priority. Susceptibility to flooding is fairly uniform in each municipality, and so only two of its barangays were selected to represent it. From each of these barangays, three households and one key informant were interviewed. This methodology continues to be refined, and is being applied to three barangays in Bataan, 15 barangays in five coastal Bulacan municipalities, and four KAMANAVA barangays. In all, we have interviewed 208 people from 53 barangays. The questionnaire data are still being analyzed using the Statistical Package for Social Sciences (SPSS). Most of the data are nominal, thus, only statistics such as frequencies and percentages were generated.

Some of our most important data are yielded by changes in water wells. Since 1998, in an area of more than 100 km^2 north of Pampanga Bay, local people have reported numerous wells that are rising out of the surrounding ground. We inform them that it is the land subsiding instead. Many wells are indoors; others are provided with box-like enclosures. At such sites, portions of floors or enclosure walls attached to the pipes buckle or shear vertically away from the rest of the structure during subsidence. If homeowners or neighbors can provide the construction dates, it is easy to calculate the rates of subsidence. Other significant information documents subsidence rates from historical changes in flooding and tidal invasion.

RESULTS

Satellite data

The analysis of 1989 and 2001 satellite images by Balboa (2002) shows that the coastal wetlands are now more sharply confined by fishpond dikes that have been raised against rising relative sea level. In northwestern Pampanga, volcanic sediment carried down from Pinatubo by the Pasig-Potrero river has reduced waterlogged areas, by enlarging its alluvial fan on the deltaic flats, and by constructing a cuspate delta about 5 km. long with an area of about 1 km^2 (Balboa and Siringan, in prep.). The Pampanga River, diked after the eruption, has also lengthened its delta to a similar degree. Lahars that have descended along the Pasig-Potrero River since the eruption and buried the town of Bacolor to maximal depths of 9 meters have built up a new swath of dry ground about 2 km. wide and 10 km. long. New waterlogged locations, each a few km^2 in area, have also appeared in Pampanga. Most notably, the area east of the lower Pampanga River, which was freed from Pinatubo sedimentation by dikes built after the eruption, is now waterlogged.

Water-well and road-raising data

Respondents report well depths in lengths and half-lengths of 20-foot pipe. No wells less than 36.6 meters (120 ft) deep display effects of subsidence, but 27 wells seated more than 36.6 meters deep have yielded subsidence rates, typically several millimeters or centimeters every year, averaging about 2.5 cm/y. These rates are consistent with the estimates based on accounts that some areas that stood above tide levels 30 years ago are now frequently flooded almost a meter deep during high tide. Subsidence rates we gathered from emergent wells have been independently verified in 2001 by geodetic engineers of the Department of Public Works and Highways (DPWH), who reoccupied six benchmarks, five of which were established in the 1950s and one in 1999 (Nippon Koei 2001). We were skeptical about anecdotal reports that roads have to be raised about 0.5 meter annually at the coastal Barangay (village) Batang Segundo in Lubao, Pampanga, until a benchmark that DPWH established there in 1999 confirmed a 0.46 cm/y subsidence rate when it was reoccupied in 2001.

Respondents have reported that roads have been frequently raised in order to keep them navigable during the rains. We need to point out that, unless care is taken to provide the roads with culverts, one unintentional result is to hinder the seaward flow of floodwaters and enhance flooding. Furthermore, most houses and lots along the roads are not raised also, and are seriously flooded even if the road stands above the water.

Enhanced flood and high tide levels reported by informants

Over the 12 years since the 1991 Pinatubo eruption, Bulacan and KAMANAVA residents report, the worst annual floods have increased in height by 0.2-1 meter. Bataan and Pampanga informants reported equivalent increases of 0.3-1 meter. These values yield subsidence rates ranging from 1.7 to 8.3 cm/y. More typical values are between 2.5 and 5 cm/y. In coastal communities, typhoons and southwest monsoons used to trigger floods that typically lasted only about 2 hours, peaking during high tides. Now, tidal flooding sometimes takes an entire day to subside. In the more inland municipalities, even moderate rains almost always cause flooding. High-tide floods already were common 12 years ago in coastal Pampanga, but since the eruption, owing to the choking of waterways by lahars, prolonged flooding has transformed Pampanga's inland municipalities into virtual wetlands. Guagua and parts of Sasmuan and Lubao are flooded for 6 months, Minalin usually for almost 9 months, Macabebe for 3 weeks to one month.

Floods have similarly become more frequent and longer-lasting in Bulacan and KAMANAVA. Closer to Manila, most coastal barangays of Malolos, Obando and Hagonoy floodwaters take from a half to an entire day to subside. In coastal barangays further north, floods take from 2 or 3 days to as much as a week to recede. Inhabitants attribute the worsening floods to siltation and encroachment of channels by fishponds. Pariahan, a small *sitio* (hamlet) in Bulacan municipality just a few hundred meters from Manila Bay, is now permanently flooded by seawater because its seawalls were damaged by typhoons.

Response of the flooding victims

We have presented our findings to numerous gatherings of local government and nongovernmental organizations since 1999, and have learned how difficult it is to convince the local people of the role of subsidence in aggravating the flooding. People are deeply attached to places and communities where they have lived for generations. For many, their ancestral homes and lots are their only assets. The government is too poor to resettle them elsewhere, and is already committed to expensive engineering solutions — which, although probably ineffective and even dangerous, the desperate flood victims are eager to believe will work.

Understandably, some people are reluctant to recognize that their own excessive, even prodigal use of groundwater contributes to subsidence and the consequent flooding. Part of the difficulty lies in the fact that the process is hidden underground. It is much easier to assign all blame to the many visible causes at the surface, like encroaching fishponds and slum housing, water hyacinths ("water lilies"), and garbage. Many do understand the consequences of excessive groundwater use but having been denied of alternative sources, they have resigned themselves to the worsening situation. Many acknowledge that free-flowing wells must aggravate the subsidence, but fear that a well might not flow again, or might yield dirty water after it is temporarily closed. Others would like to take action, but do not know to whom they can turn.

Unlike an earthquake or volcanic eruption, the worsening floods are gradual, and permit temporary, stop-gap solutions. Optimism is rampant during the few flood-free months, and people want to forget the wet and discomfort. We can only fervently hope that it will take less than a catastrophic deluge to educate the people and bring about proper mitigation of this continuing "slow-motion catastrophe". A worst-case scenario would involve simultaneous record tides raised by long-lasting storm surges and waves and sustained rains like those that caused Luzon's record floods in 1972. In KAMANAVA alone, more than two million Filipinos are at risk.

Population change 1990 to 2000

From 1990 to 2000 the Philippine population grew 26 percent, to 76.5 million, but the five-year rate of increase slowed from 13 percent in 1995 to 11.5 percent in 2000 (POPCOM 2000). The 4.2 percent annual growth rate is exceeded in East Asia only by Singapore's 4.3 percent and those of Brunei and Cambodia, each 2.4 percent.

Philippine coastal plains are home to 63 percent of the country's population, and are also where farming and aquaculture are most extensive. Preeminent among these is the coastal-estuarine region that surrounds northern Manila Bay, which increased in population much more rapidly than the nation as a whole, by 39 percent from 4,907,519 in 1990 to 5,690,861 in 2000 (POPCOM 1990, 1995, 2000). Much of this growth is related to proximity to Metro Manila; of the three provinces, Bataan is the farthest and has the smallest coastal population, only 202,310 in 2000 after growing 28 percent since 1990 (Table 1).

Pampanga's coastal and estuarine population grew from 903,757 in 1990 to 1,082,892 in 2000, an increase of 20 percent. Although large, this rate was only about half that of

Table 1. Population Growth from 1990 to 2000 in Communities of the Coastal Plains Surrounding Northern Manila Bay

				% CHANGE		
PROVINCE/Town	**1990**	**1995**	**2000**	**1990-1995**	**1995-2000**	**1990-2000**
BATAAN	**158,290**	**177,178**	**202,310**	**11.9**	**14.2**	**27.8**
Dinalupihan	58,172	65,159	76,145	12.0	16.9	30.9
Hermosa	34,633	38,764	46,254	11.9	19.3	34.1
Orani	43,494	48,695	52,501	12.0	7.8	20.7
Samal	21,991	24,560	27,410	11.7	11.6	24.6
BULACAN	**1,464,137**	**1,732,727**	**2,172,364**	**18.3**	**25.4**	**48.4**
Angat	34,494	39,037	46,033	13.2	17.9	33.5
Balagtas (Bigaa)	42,658	49,210	56,945	15.4	15.7	33.5
Baliuag	89,719	103,054	119,675	14.9	16.1	33.4
Bocaue	67,423	69,718	86,994	3.4	24.8	29.0
Bulacan	48,770	54,236	62,903	11.2	16.0	29.0
Bustos	34,965	41,372	47,091	18.3	13.8	34.7
Calumpit	59,042	70,839	81,113	20.0	14.5	37.4
Guiguinto	44,532	52,575	67,571	18.1	28.5	51.7
Hagonoy	90,212	99,423	111,425	10.2	12.1	23.5
Malolos	125,178	147,414	175,291	17.8	18.9	40.0
Marilao	56,361	68,761	101,017	22.0	46.9	79.2
Meycauayan	123,982	137,081	163,037	10.6	18.9	31.5
Norzagaray	33,485	51,015	76,978	52.4	50.9	129.9
Obando	46,346	51,488	52,906	11.1	2.8	14.2
Paombong	32,052	33,149	41,077	3.4	23.9	28.2
Plaridel	52,954	66,355	80,481	25.3	21.3	52.0
Pulilan	48,199	59,682	68,188	23.8	14.3	41.5
San Ildefonso	59,598	69,319	79,956	16.3	15.3	34.2
San Jose del Monte	142,047	201,394	315,807	41.8	56.8	122.3
San Miguel	91,124	108,147	123,824	18.7	14.5	35.9
San Rafeal	49,528	58,387	69,770	17.9	19.5	40.9
Santa Maria	91,468	101,071	144,282	10.5	42.8	57.7
PAMPANGA	**903,757**	**960,767**	**1,082,892**	**6.3**	**12.7**	19.8
Apalit	62,373	65,720	78,295	5.4	19.1	**25.5**
Arayat	73,189	85,940	101,792	17.4	18.4	39.1
Bacolor	67,259	13,097	16,147	-80.5	23.3	-76.0
Candaba	68,145	77,546	86,066	13.8	11.0	**26.3**
Guagua	88,290	95,363	97,632	8.0	2.4	10.6
Lubao	99,705	109,667	125,699	10.0	14.6	26.1
Macabebe	55,505	59,469	65,346	7.1	9.9	**17.7**
Masantol	41,964	45,326	48,120	8.0	6.2	14.7
Mexico	69,546	91,696	109,481	31.8	19.4	57.4
Minalin	34,795	35,670	35,150	2.5	-1.5	**1.0**
San Fernando	157,851	193,025	221,857	22.3	14.9	40.5
San Simon	30,678	35,474	41,253	15.6	16.3	34.5
Sto. Tomas	33,309	29,628	32,695	-11.1	10.4	**-1.8**
Sasmuan	21,148	23,146	23,359	9.4	0.9	10.5
KAMANAVA	**1,571,148**	**2,036,847**	**2,232,295**	**29.6**	**9.6**	42.1
Kaloocan City	763,415	1,023,159	1,177,604	34.0	15.1	54.3
Malabon	280,027	347,484	338,855	24.1	-2.5	21.0
Navotas	187,479	229,039	230,403	22.2	0.6	22.9
Valenzuela City	340,227	437,165	485,433	28.5	11.0	42.7
TOTAL	**4,097,332**	**4,907,519**	**5,689,861**	**19.8**	**15.9**	38.9

the entire region, probably due in large part to the 1991 Pinatubo eruption and its aftermath. The most dramatic decline was experienced by Bacolor municipality, the one most damaged by lahars, which descended down the Pasig-Potrero River. After burial of the town proper to an average depth of 6.5 meters by lahars of 1991, 1994 and 1995 (Crittenden and Rodolfo 2001), Bacolor had lost over 80 percent of its inhabitants, and, despite subsequent returnees, by 2000 had suffered an overall decadal decline of 76 percent. Santo Tomas municipality, farther downstream from Bacolor, suffered from heavy volcanic siltation and lost 11 percent of its population by 1995, but had recovered most of this loss by 2000, presumably because many evacuees returned. Nevertheless, Santo Tomas also experienced a small decadal population decline, -1.5 percent.

It is notable that many of the most flood-prone Pampanga municipalities experienced the slowest decadal population growth, and declined even more during the post-lahar period 1995 to 2000; for example, the Santo Tomas growth of 10.4 percent was anemic by regional standards, and may reflect enhanced flooding. Even more flood-prone are the towns of Minalin, Sasmuan, Guagua, and Masantol, which between 1990 and 2000 respectively grew at rates of only 1.0, 10.5, 10.6, and 14.0 percent. Furthermore, the populations of all these towns, together with those of Bacolor and Santo Tomas, experienced slowing growths between 1995 and 2000.

Proximity of Bulacan to Manila is largely responsible for the extremely rapid growth of its coastal population: 48.4 percent from 1990 to 2000, and 25.4 percent from 1995 to 2000. Strikingly, the notoriously flood-prone and tidally invaded town of Obando lagged far behind all other Bulacan municipalities, growing only 14.2 percent from 1990 to 2000, and only 2.8 percent over the last five years of that period. Other especially flood-prone Bulacan municipalities growing at below-average rates include Hagonoy, Paombong, Bocaue, Bulacan, and Meycauayan.

KAMANAVA is officially part of Metro Manila, but lagged in growth behind Bulacan, mainly because Malabon shrank by 2.5 percent, and Navotas grew only 0.6 percent. It is probably no coincidence that those two metropolitan municipalities are the most flooded by rainstorms and high tides. Between 1995 and 2000, Malabon actually lost population, Navotas had negligible growth, and both Kalookan and Valenzuela experienced sharp declines in growth rates.

DISCUSSION

Our research involved both natural and social science methods. If either approach had been used alone, we would not have attained our most valuable results.

Groundwater, subsidence, and relative sea level

Coastal floods are increasingly bothersome occurrences everywhere in the world where cities satisfy the water needs of rapidly growing populations by pumping too much water out of the ground, causing the land to subside. Tokyo, Osaka, Shanghai, Bangkok, Hanoi and Jakarta are other metropolises on East Asian deltaic and coastal plains that have experienced this serious problem (Table 2). An excellent correlation has been established between the apparent rise in sea level and increasing groundwater usage in Metro Manila since the 1960s (Siringan and Ringor 1998:29-40, Siringan and Rodolfo, in press).

How intensive groundwater extraction causes land to subside has been understood for a long time (e.g., cf. Lofgren 1965, Poland 1984). Most deltaic river sediment is mud, with lesser layers of sand and gravel. Even without human activity, deltas subside naturally as these sediments continually accumulate. They "autocompact" the accumulating weight over each mud layer squeezes water out of it, compressing it, and causing the surface to slowly but continuously subside, at rates of no more than a few millimeters per year. Autocompaction rates around Manila Bay should be comparable to those observed on the Po delta of Italy (0.75 mm/y — Carminati and Di Donato 1999), and the Mississippi delta in the United States (0.9-3.7 mm/y — Kuecher et al., 1993; average 1.8 mm/y — Penland et al. 1988). Such rates are only of the magnitude of global sea level rise.

The sandy and gravelly layers encased in the thick delta muds are called "aquifers" – Latin for "water bearers" — because rainwater that percolates into the ground is stored in pores between their grains, which are relatively large, and thus easy for water to flow through and for wells to tap. Mud contains much more water than gravel or sand, but its pores are so much finer that water cannot

Table 2. Subsidence of East Asian Cities due to Groundwater Withdrawal

		SUBSIDENCE		
LOCATION	PERIOD	meters	cm/y	Reference
Tokyo, Japan	1900-1976	4.6	2.7	Yamamoto, 1984
Osaka, Japan	1934-1968	2.8	8.2	Yamamoto, 1984
Shanghai, China	1921-1965	2.63	6.0	Shi and Bao, 1984
Hanoi, Vietnam	1988-1993	0.1-0.3	2-6	Nguyen, 2001
Manila Bay, Philippines	1991-2003	0.2-1.0	1.7-8.3	This paper
		0.3-0.6	2.5-5.0*	
	1962-2002	**average 3.0**		
Bangkok, Thailand	1980-1990	0.5-1.0	5-10	Anonymous, 2001
	2001		1.5-2.2**	
Jakarta, Indonesia	1991-1999	0.3-0.8	4-10	Abidin et al., 2001

* More typical values

**After raising taxes on groundwater

flow through them very easily. If, however, water is pumped out of an aquifer faster than it can be replenished by natural percolation, the pressure is reduced in the aquifer, which forcibly sucks water out of the surrounding mud to refill its pores. In effect, over-usage of groundwater can speed up natural compaction and subsidence by an order of magnitude. It is important to note that dewatering of clays and resulting subsidence are irreversible. Water-well data from Pampanga document that subsidence rates over the past 30 years commonly exceeded 3 cm/year. If subsidence from groundwater withdrawal is the only significant mechanism that caused the rise in relative sea level since 1991 indicated by our sociological data, it has accelerated to as fast as 8.3 cm/y.

It is important to recognize that groundwater use by individual families may not be the greatest producer of land subsidence. People complain that their domestic artesian wells stop flowing when large-volume pumps start up to irrigate large plantations or when fishponds are flushed and refilled. As our work has expanded from Pampanga eastward into Bulacan and KAMANAVA, we have become aware of the great quantities of groundwater that are extracted for fishponds. A current aquacultural practice is to provide the fish with too much feed. What is not eaten is consumed by bacteria, which use up the oxygen dissolved in the water. Effectively poisoned, the water is flushed into the sea – deteriorating the environment of free-living species to the detriment of Bay fishers – and replaced with great quantities of groundwater. Many fishponds have been illegally enlarged by encroaching into tidal channels and are guarded by heavily armed private armies, and so we cannot measure the pumped volumes. To be assessed and regulated, this usage would require government action, backed by court injunctions and troops, if necessary. In the meantime, we can only speculate that fishpond pumps may cause as much land subsidence as it does in the Yun-Lin area of Taiwan, where extensive fishponds use so much groundwater that they have caused the land to subside 0.66 meter from 1989 to1997 (Liu et al. 2001), causing an 8.2 cm/y subsidence rate. Either coincidentally or significantly, that rate is virtually equal to the maximum 8.3 cm/y our sociological data yield for Bulacan.

Large volumes of groundwater also are used for the recreational purposes of the well-to-do. Golf courses and swimming pools are maintained by groundwater during the dry seasons, and regulations of these activities are also not enforced.

Government response

Our research has obvious relevance for the Department of Agriculture, which seeks to anticipate and adjust to rising regional sea level with timely and efficient land-use planning. Other government responses at both the national and local levels have been disappointing. Indeed, to woo and reward voters, local politicians actually enhance the subsidence by needlessly proliferating wells. Driven by the three- and six-year electoral cycles, government efforts seem to favor short-term political contingencies over efficacy, and largely consist of "palliative" measures — soothing the anxious public by displaying measures that actually accomplish little.

An excellent case in point is the "Third River" flood-control channel in Pampanga (Nippon Koei 2001: 1-1- 8-1). Designed to alleviate the chronic flooding in Guagua, Lubao and Sasmuan towns, the channel was positioned in an area known by the Japanese and other foreign consultants to be flooded during maximum tide. Worse, it follows very closely the locus of fastest subsidence that these consultants measured and mapped for DPWH (Siringan and Rodolfo 2002). The project was approved and initiated long before Filipino scientists outside of DPWH learned of such details.

The most benign interpretation of why the channel was thus situated precisely where it would be least effective could well be the correct one: that this inappropriate site is the only one the landowners will permit. Local authorities often complain that the national government planners do not consult them sufficiently (Rodolfo 1995: 262), and is frequently remiss in remunerating the owners of the property that it expropriates by power of eminent domain (e.g, cf. , Lacuarta 1993). Owners resist, and political pressures come to bear. The Third River project has encountered public demonstrations, newspaper accounts of outraged citizenry (Cervantes 2001, Orejas 2001a) and angry legislators (Orejas 2001b). Armed citizens may even confront field engineers. A political settlement may be arrived at (Orejas 2002), but only at the expense of the ability of the project to accomplish its physical purpose. Rights-of-way owners are least reluctant to lose land if it has already been devalued by flooding and tidal invasion.

The project must go on, however, because interests other than those of hazard mitigation come into play. While still in office, President Joseph Estrada, a foremost authority on Philippine corruption, reported at a conference in Seoul that government projects routinely lose 20 percent to graft and corruption (Marfil 1999). That figure is over and above the 10 percent that Philippine law allows project proponents in congress to claim as finders' fees. The money appropriated for the Third River project was about a billion pesos (Orejas 2002, Roxas 2002).

The history of how the government built and maintains dikes to contain the lahars that rains continue to trigger 12 years after the 1991 Pinatubo eruption is instructive (Rodolfo 1995: 203, 291, 299, 302-304). Initially, little effort was expended to determine the properties and behaviors of lahars in order to engineer properly against them. Instead, what appeared to guide the plans was how much money the legislature might be willing to disburse. Dikes thus restricted in expense and quality were built, failed, and were rebuilt, either in original form or with token improvements in design, only to fail again. Nevertheless, funds continue to be appropriated for their repair (Orejas 2003b).

Containing floods by confining a channel with dikes is a nineteenth century approach that in the new millennium is being questioned and successfully opposed in developed countries. Decision makers in developing countries have not yet learned that the practice ultimately is counterproductive in two ways. First, it at best can only postpone floods. It traps sediments that raise the channel bed, thus requiring that the dikes be raised again and again. This can go on only so long; at some point, if they have been raised to the limit, or if funds for repair are lacking, a hundred-year flood will top and breach them, releasing floods of catastrophic magnitude, like the 1993 Mississippi Valley disaster in the United States. Second, the sediments trapped in the channel are denied to the floodplains that are intrinsic, vital parts of the river's domain and ecology. If not tampered with, deltas slowly build seaward because the sediment that floods normally deposit on the floodplains more than compensates for the loss of elevation from autocompaction and subsidence. Ironically, building dikes to prevent flooding arrests this natural compensative process, and thus in the long run contributes to flooding.

Another expensive project of doubtful efficacy is the project designed to protect KAMANAVA both from storm and tidal flooding, a complex of polder dikes, river walls equipped with flood-control gates, and pumps. The project is being funded with Japanese loans that burgeoned from P2.15 billion in 1998 to 3.9 billion in 2002 (Cruz 2002) to P5 billion in 2003 (Nocum 2003), a growth that likely reflects ad hoc planning, and could well project even higher ultimate costs.

The designers plan to pump out floodwaters during low tides, but sustained southernly winds can raise sea level significantly for days, rendering the structure not only ineffective, but quite possibly enhancing the hazard by giving to the endangered an undeserved sense of security and complacency. Furthermore, plans for another ongoing DPWH project produced by the same consulting firm (Nippon Koei 2001: 2-6 – 2-8, T-1) report that Manila can experience southerly wind speeds exceeding 220 km/h (34 m/s), and waves 3.7 m high have been recorded at Manila's port. Typhoon winds and waves historically have been so severe in Manila Bay that the U. S. Navy declared it an unsafe haven during typhoons:

> During [typhoon] Patsy, which passed over Manila [in 1970], high winds and seas sank 21 fishing boats near the North Harbor. Larger vessels dragged anchor or broke loose. Six of them were driven aground or smashed against Roxas Boulevard … [Typhoon] Ora repeated this tragedy a few years later [in 1972], when another six oceangoing vessels were swept into the breakwater (Brand et al. 1979: 297).

For the KAMANAVA project, the Japanese consultants released a "Final Report" on 28 August 1998 (Konekahara 1998), an "Interim Report" almost four years later (Kin 4 May 2001), and a "Sectoral Report" dealing principally with soil mechanics dated August 2001. None of these documents mention the energies and durations of typhoon winds, the sizes, energies, and durations of the surges and storm waves they generate, or the construction details that give the structures a chance of containing, or even surviving, such conditions.

To protect the northern KAMANAVA area that is already at or below mean sea level, the plans include a polder dike 8.6 km. long, composed only of earth, standing only 2.1 meters above mean sea level. Even discounting storm waves, surges driven by typhoon winds can raise sea level temporarily to overtop this height. The 2001 Sectoral Report acknowledged 2.57 cm/y of subsidence resulting from groundwater use. Even though that figure probably is already too low, a rate of only 0.65 cm/y was incorporated into the design to minimize the role of continuing subsidence and its implications for future maintenance costs. Responding to criticism (Orejas 2003a), a DPWH official and a consultant denied the contents and omissions of their own reports and insisted that their designs had taken storms and waves into account (Nocum 2003, *Philippine Star* 2003).

Learning about mistakes the Japanese made in building their own Kansai International Airport may help counteract an unfortunate Filipino tendency to accept foreign expertise too uncritically. The airport was built on an artificial island in Osaka Bay at a cost of 17 billion U.S. dollars and opened in 1994. The planners projected it to sink about 11.6 meters in 50 years. It took only six years to do so (Yamaguchi 2000).

We must point out that subsidence and aggravated flooding from groundwater use share the root cause of so many other Philippine problems. Along with increasing deforestation, soil erosion and lethal landslides, garbage disposal, over-crowded classrooms, joblessness, and, to the detriment of the Filipino family, the increasing economic reliance of the country on overseas workers, it stems from rapid population growth. Given the national fondness for children and lack of political will to limit population size, all such problems can only be expected to worsen inexorably.

Regional population statistics (Table 1) may already be reflecting the environmental deterioration of the region. Overall five-year Metro Manila growth has slowed down from 18.5 percent in 1995 to 5.1 percent in 2000, and it is widely felt that the quality of life there, particularly in coastal areas, is being worsened by flooding. The most flood-prone communities that display sharply declining or even negative growth include Malabon and Navotas in KAMANAVA and the towns of Orani in Bataan, Obando in Bulacan, and Minalin, Sasmuan and Guagua in Pampanga.

SOME RECOMMENDATIONS

Reducing groundwater usage

Abuse of our groundwater is the most serious cause of increased flooding and demands our most urgent attention. Barring a successful campaign to reduce population growth, the only remedy is to drastically curtail its use. Two approaches are indicated: First, land subsidence would be slowed to whatever extent groundwater is replaced with surface sources. The region is entirely bordered by mountains, on which small dams could be built to store water, both in surface reservoirs as well as underground. On the family level in other places in the world such as Bermuda, the roof of every house is built to funnel all rainwater into cisterns.

Second, if groundwater is to continue to be a major source of water, it must be protected by proper, regulated use. A good Water Code and Implementing Rules and Regulations were promulgated by the National Water Resources Council decades ago (NWRCP 1979), but its requirements are virtually ignored, beginning with the first one: drilling permits. They dictate that pump users must consider the possibility of "mining" and its other bad consequences besides land subsidence. Mining – drawing out more water than the environment can replace — sucks progressively deeper wells dry as it lowers the water table. In coastal areas, it causes "saltwater intrusion" — it draws in salty groundwater from beneath the ocean that permanently poisons the freshwater aquifers. The Water Code requires that free-flowing groundwater be conserved with valves, and even specifies how far apart wells can be spaced depending on how much water is drawn from them. One change would be necessary, for the code exempts wells shallower than 10 meters. The topmost sediment layer usually is the most waterlogged and the most easily dewatered and compacted, and shallow wells are great in number.

To be successfully implemented, the code must limit wells to a reasonably small, enforceable number, properly run and regulated by local governments. People would have to pay for water piped from such sources, but appropriate payment for this fundamental resource would engender respect for it, and its conservation. Bangkok was able to reduce its subsidence from 5-10 cm/y to about 2 cm/y because the principal wells were industrial. The politico-economic solution was to raise taxes on wells until it became cheaper to import surface water (Government of Thailand 2001: 46).

In a just world, efficient regulation properly would begin with the most prolific and wasteful users, but fishpond owners, and those who enjoy the use of resorts and golf courses, are wealthy and influential.

Before successful regulation, education; people should not only be encouraged and exhorted to conserve groundwater, but also empowered to do so. For example, there is some justification for the fear that turning artesian wells off and on may soil the water, or permanently divert the flow to other wells. New wells can be equipped with gravel packs to avoid those problems (Driscoll 1986: 438-427), and research is needed to determine if existing wells can be retrofitted with such devices.

Other long-term flood-mitigating measures

For the better known causes of flooding, the answers are also well understood, easily stated, but difficult to implement. The nation must stop using waterways as garbage dumps and housing sites. Original channels widths must be restored where illegally widened fishponds have been choking them. Floodwaters should be allowed to occupy larger floodplain areas, as nature has intended.

Reforestation is very important in the long term. Upland forests reduce and delay runoff by increasing infiltration, which also replenishes the groundwater. By protecting the soil, they reduce erosion and siltation in lowland channels; further, if the runoff from the uplands are carrying less sediment than they are capable of transporting as they arrive at the coastal plains, they will erode and unclog the waterways during floods. If any of these measures are to be effective, they cannot be performed town by town or even province by province. Nationally coordinated efforts are needed because part of the flood problem in the coastal lowlands lies in provinces not affected by the flooding, for example, those with deforested slopes.

The greater part of the Philippine population, residing on coastal plains, is squeezed, figuratively, between the two jaws of a vise: its own rapid growth, and the subsidence and flooding generated by its own use of groundwater. Other coastal areas that could be experiencing the same phenomena include Lingayen Gulf, Davao, and Agusan.

We may take bleak comfort in realizing that subsidence from groundwater over-usage is a process that is self-enhancing at present, but must be self-limiting in the future, even without proper regulation. As the growing population continues to extract excess amounts of groundwater, subsidence, and attendant tidal incursion and storm flooding can only get worse. Eventually, however, either or both of two consequences will force the exorbitant use of groundwater to slow down. First, the groundwater may be so depleted, or so contaminated by saltwater intrusion that its use will have to stop. Secondly, subsidence and attendant tidal and storm flooding may render portions of the coastal plains no longer habitable, which would also result in reduced pumping. In the end, though, whatever subsidence has happened will be permanent, because the dewatering and compaction of clays is an irreversible process.

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