# Global sea-level rise is recognised, but flooding from anthropogenic land subsidence is ignored around northern Manila Bay, Philippines

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*Land subsidence resulting from excessive extraction of groundwater is particularly acute in East Asian countries. Some Philippine government sectors have begun to recognise that the sea-level rise of one to three millimetres per year due to global warming is a cause of worsening floods around Manila Bay, but are oblivious to, or ignore, the principal reason: excessive groundwater extraction is lowering the land surface by several centimetres to more than a decimetre per year. Such ignorance allows the government to treat flooding as a lesser problem that can be mitigated through large infrastructural projects that are both ineffective and vulnerable to corruption. Money would be better spent on preventing the subsidence by reducing groundwater pumping and moderating population growth and land use, but these approaches are politically and psychologically unacceptable. Even if groundwater use is greatly reduced and enlightened land-use practices are initiated, natural deltaic subsidence and global sea-level rise will continue to aggravate flooding, although at substantially lower rates.*

**Keywords:** enhanced flooding, groundwater overuse, land subsidence, regional sea-level rise, tidal incursion

## Introduction

Since 1997, we have been using both physical methods and sociological surveys to study worsening floods and tidal incursions in the heavily populated and cultivated region around northern Manila Bay (Siringan and Rodolfo, 2003; Rodolfo et al., in press). Southeast of Pinatubo Volcano since its 1991 eruption, one cause has been channel filling by sediments from floods and lahars (flowing slurries of volcanic debris). Long before 1991, however, and in areas that received no Pinatubo sediment, regional floods were worsening. They are blamed on upland deforestation, rapid urbanisation, channel encroachment by squatters and fishponds (Nippon Koei Co., Inc., 2001) and garbage dumping in estuaries (Orejas, 2000).

Only recently (Tacio, 1999a; 1999b) have the Philippine public and the country's decision-makers become aware that global warming is raising the world's oceans by one to three millimetres per year (Intergovernmental Panel on Climate Change, 2001). Most sectors of the government, though, are oblivious to, or ignore, the fact that groundwater overuse is causing the plains around northern Manila Bay to subside more than 10 times faster—by centimetres and even more than a decimetre per year—

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even though the government's Department of Public Works and Highways (DPWH) has verified this geodetically.

In this paper, we first review how overuse of groundwater causes subsidence and discuss the East Asian scope of the problem, other consequences of groundwater overuse and efforts taken to control it. We then look at the physical and climatic setting of north Manila Bay's flood-prone delta plains, update the results of our physical and sociological research and describe population trends that might reflect the response to slow inundation. Our main topic, however, is how the government and the public are responding to the news about groundwater over-pumpage and land subsidence. We report what we experienced as we shared our findings with affected communities and local leaders, outline three expensive but ineffective flood-control projects undertaken by the government and refer extensively to newspaper coverage as it reflects public and private attitudes towards flooding and its mitigation. Finally, we offer some conclusions and recommendations for resolving the problems.

## Background

### Groundwater overuse and land subsidence

Fluvial sediments, such as those that underlie the deltaic coastal plains surrounding northern Manila Bay, are mostly mud with lesser layers of sand and gravel. Even without human activity, such sediments 'autocompact', meaning that the accumulating weight over each mud layer squeezes water out of it, compressing it and causing the surface to subside at rates of no more than a few millimetres per year. Autocompaction rates around Manila Bay (Soria et al., 2005) are only of the magnitude of global sea-level rise, comparable to those observed on the Po delta of Italy (0.75 millimetres per year) (Carminati and Di Donato, 1999), and the Mississippi delta in the US (0.9–3.7 millimetres per year) (Kuecher et al., 1993), averaging 1.8 millimetres per year (Penland et al., 1988). Subsidence from groundwater overuse is commonly one or even two orders of magnitude more rapid.

How excess groundwater use causes land subsidence has been known for a long time (Terzaghi, 1925; Tolman and Poland, 1940), and the theory is summarised admirably by Galloway et al. (2001). In river deltas, groundwater is stored in and recovered from sandy and gravelly *aquifer* ('water bearer') layers. Aquifers are contained by interbedded *aquitards,* layers of clayey sediment that are much more porous and contain significantly more water, but, being of a very fine grain, have a great deal of grain surface to offer frictional resistance and *retard* the through-flow of water—hence their name.

Deltaic sediment columns are supported in part by the fluid pressure of their pore waters. When water is extracted from an aquifer, support is transferred from its fluid pressure to the sediment grains comprising its granular skeleton, which is somewhat compressed, commonly causing the ground to subside a few centimetres. If groundwater extraction is not excessive, that compression and subsidence may be fully reversed when precipitation recharges the aquifer. Excessive pumping of an aquifer, however, reduces its pressure below that in the adjacent aquitards, from which it sucks water. Importantly, the reduced aquitard volumes and the resulting loss of surface elevation are permanent. Using radar interferometry in the Ping Tung plain of southern Taiwan from 1996–99, Chang et al. (2004) measured three to six centimetres of annual subsidence that occurred only during the dry seasons of heavy pumpage.

## Land subsidence in East Asia

Every part of the world that withdraws groundwater at rates greatly exceeding those of recharge experiences serious subsidence. A 65,000 square kilometre area centred on Houston, Texas, in the US is a well-studied instance (Kasmarek and Robinson, 2004). Maximum subsidence there from 1906–95 was more than three metres, averaging 3.4 centimetres per year. The problem is especially serious in East Asian coastal zones. There, many metropolitan areas have experienced worsening floods attributed to several centimetres per year of subsidence due to excessive groundwater withdrawal (see Table 1 and references therein). These include 14 of China's 36 coastal and deltaic cities (Hu et al., 2004); the six of these that are sinking at rates of four centimetres per year or more are listed in Table 1.

Subsidence from excessive groundwater use is not limited to urban areas. One of the most notorious instances is the 8.8 metres of lowering of the heavily cultivated, semi-arid San Joaquin Valley in California, US, at rates of 16–26 centimetres per year from 1926–72 (Larson et al., 2001). Expanding coastal aquaculture in East Asia is a principal cause of widespread subsidence (Chua, 1992). The rapidly subsiding fishpond areas in the plains along the 80 kilometres of Taiwan's western coasts (Table 1) are of special interest because their geologic, climatic and land-use settings are very similar to those of northern Manila Bay.

## Corollary effects

Enhanced flooding and tidal incursion are not the only deleterious effects of subsidence. It can trigger minor seismicity (Yerkes and Castle, 1976; Davis et al., 1995). Differential settling has caused ground cracking and damage to buildings in the Shiroishi plain of Kyushu in Japan (Don et al., 2005), and in Jakarta, Indonesia (Abidin et al., 2001). Ramos (1998) attributed to excessive groundwater use up to a few centimetres of vertical movements per month at numerous faults, causing damage to buildings, roads and railways in Muntinglupa, Metro Manila. Lowering of a coastal plain in western Taiwan has enhanced wave erosion (Lin, 1996), as it has in Bangkok, Thailand (Sinsakul, 2000).

In coastal areas, excessive groundwater extraction draws salty groundwater inland, permanently poisoning the aquifers, as far inland as 4.5 kilometres in Taiwan's Ping Tung Valley (Chang et al., 2004). Overuse may also poison groundwater. Liu et al. (2003) attributed widespread arsenic poisoning in the 'blackfoot' disease area of Yun-Lin on the western Taiwan coast to dissolved oxygen brought into aquifers in which it reductively dissolves arsenic-rich iron oxyhydroxides.

**Table 1** Subsidence and corollary effects besides enhanced flooding due to groundwater withdrawal in selected East Asian coastal areas

| | | | Subsidence (centimetres (cm)) | | | |
|---|---|---|---|---|---|---|
| **Location** | **Land use** | **Period** | **Cumulative** | **Rate (cm/year)** | **Corollary effects** | **Reference** |
| **Japan** | | | | | | |
| Tokyo | Metropolis | 1900–76 | 440 | 2.7 | | Yamamoto, 1984a |
| Osaka | Metropolis | 1934–68 | 280 | 8.2 | | Yamamoto, 1984b |
| Shirioshi plain, Kyushu | Agriculture | 1960–98 | 123 | 3.2 | Ground fissures<br>Saltwater intrusion | Don et al., 2005 |
| **China** | | | | | | |
| Hangu City | Metropolis | 1980–97 | >100 | 5–9 | | Shearer, 1998 |
| Shanghai | Metropolis | 1921–65 | 263 | 6.0 | | Zhang et al., 2002 |
| | | 2002–03 | | 1.3 | | Chai et al., 2005 |
| Tianjin | Metropolis | 1959–2003 | 306 | | | Hu et al., 2004 |
| | | 2003 | | 0.8–5.6, max. 16 | | |
| Suzhou | Metropolis | 1960–2003 | 110 | 4–5 | | Hu et al., 2004 |
| Changzou | Metropolis | 1960–2003 | 90 | 4–5 | | Hu et al., 2004 |
| Jiaxing | Metropolis | 1960–89 | 60 | 5 | | Hu et al., 2004 |
| **Taiwan** | | | | | | |
| Taipai | Metropolis | Since 1970s | ~250 | 10 | Infrastructure damage<br>Building instability | Stabel and Fischer, 2001 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Choshui delta, including *Yun-Lin Basin | Aqua and agriculture | 1969–2001<br>1985–94<br>1998–2001 | 10–130 | 5.6<br>20<br>3–15 | *Arsenic poisoning<br>Coastal erosion<br>Saltwater intrusion | Liu et al., 2004<br>*Liu et al., 2003 |
| Pei-Kang—Tseng-Wen deltas | | 1955–95<br>1991–92 | | 5–10<br>6–20 | | Lin, 1996 |
| Pingtung plain | | 1996–99 | | 3–6 | | Chang et al., 2004 |
| **Vietnam** | | | | | | |
| Hanoi | Metropolis | 1988–93 | | 2–6 | Ground fissures | Thu and Fredlund, 2000 |
| | | 1998 | | 2 | Building damage | Giao and Ovaskainen, 2000 |
| **Philippines** | | | | | | |
| Manila | Metropolis | 1991–2003 | >100 | 5–9 | Ground fissures | Siringan and Rodolfo, 2003 |
| Pampanga delta | Aqua and agriculture | | >100 | 3–9 | Saltwater intrusion | This report |
| **Thailand** | | | | | | |
| Bangkok | Metropolis | 1978–81 | | 5–10 | Saltwater intrusion | Sinsakul, 2000 |
| | | 1989–90 | | 1–3 | Ground fissures | |
| | | 1980–90 | | 5–10 | Building damage | Prinzl and Nutaleya, 1987 |
| | | 1992–2002 | | 3–4 avg.<br>>8 max. | | Shibuya et al., 2003 |
| **Indonesia** | | | | | | |
| Jakarta | Metropolis | 1980–99 | 260 | | Building damage | Abidin et al., 2001 |
| | | 1982–91 | | 8.9 | Saltwater intrusion | |
| | | 1991–97 | | 26.7 | | |
| | | 1997–99 | | 10.0 | | |

### Control

Phienwej et al. (1998) conducted experiments in Bangkok to determine if subsidence can be reversed by pressurised injection of water. Only aquifers can respond to such measures, of course, and only a few millimetres of elevation were restored. Aquitard shrinkage, being irreversible, can only be slowed or stopped by curtailing pumpage.

The first requirement for combating subsidence is precise elevation measurements of the affected terrain. For this purpose, traditional levelling and satellite global positioning have been applied (Bitelli et al., 2000; Abidin et al., 2001). Satellite radar interferometry with sub-centimetre vertical precision is increasingly being used (Stabel and Fischer, 2001; Chang et al., 2004; Leuro, 2004). These data must be augmented by comprehensive assessments of groundwater pumpage, and by a study of the stratigraphy, porosity, permeability and other geotechnical properties of each aquifer and aquitard. A good example of such a study is that of Liu et al. (2004) on the Choshui River delta in Taiwan.

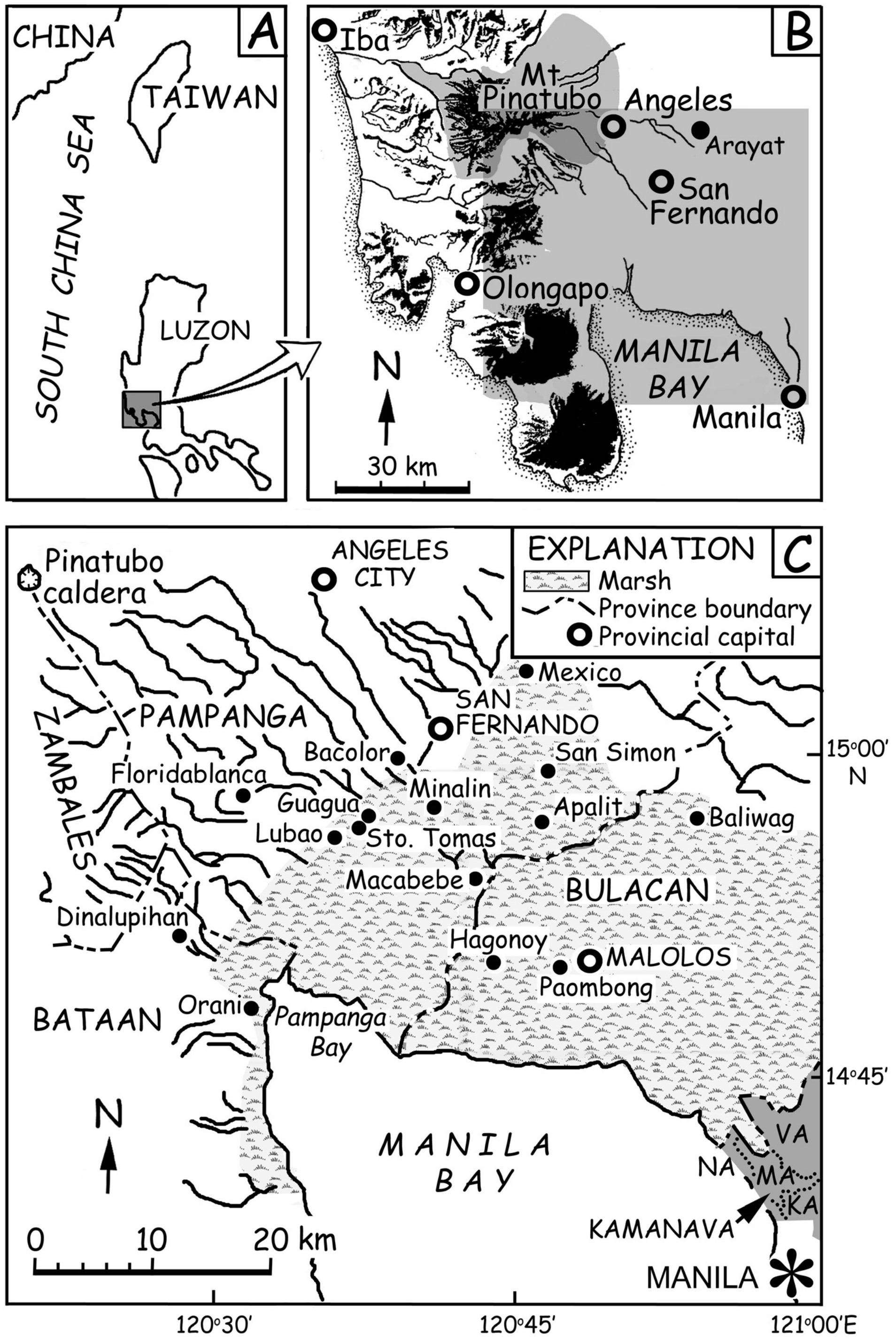
The studies of Larson et al. (2001) on the Los Banos–Kettleman area in California, and Kasmarek and Robinson (2004) on the Texas Gulf Coast aquifer, exemplify how such data are used to determine permissible pumpage. For the Yun-Lin aquaculture area of Taiwan, Gau and Liu (2001) devised an optimum-yield model to optimise water use, balancing economic profit and environmental protection. Efforts to decrease pumpage and subsidence in rural areas include soil-water management (Jin et al., 1991) and reducing planted areas and recycling urban wastewater for rural irrigation (Kendy et al., 2003). Bangkok, Osaka, Shanghai, Tokyo and other cities[2] have restricted water use to counter water-table declines and subsidence.

Application of such ameliorative measures in the Philippines can only begin after the national government recognises that the problem exists, and makes the pertinent offices and the public aware of the scope of the problem.

## Physical setting of, and worsening floods in, Manila Bay

Manila Bay is bordered by river deltas in the provinces of Bataan, Bulacan and Pampanga, and northern Manila's KAMANAVA, an acronym derived from the names of the suburbs of Kaloocan, Malabon, Navotas and Valenzuela (Figure 1). The plains comprise almost 3,000 square kilometres, extending southward from Angeles City and Arayat town to the coast, which stretches from northeastern Bataan eastward and southward to KAMANAVA (Figure 1). The coastal plains are so low and flat that the one-metre elevation extends 10–20 kilometres inland. Thus, normal spring tides only 1.25 metres high (Siringan and Ringor, 1998) extend many kilometres upstream, and even small rises in relative sea level translate into large inland encroachments. The more seaward flats, which are marshy and cut by numerous tidal inlets, are occupied almost entirely by fishponds that increasingly encroach into channels and expand northward. Rice paddies still above tidal influence, with two annual crops, eventually are converted into fishponds as the sea slowly expands northward.

**Figure 1** The area of fluvial plains surrounding northern Manila Bay



**Notes:** A and B = geographic setting; C = detailed map of the shaded rectangular area in B. Base maps are: National Mapping and Resource Information Authority (1991) 1:250,000 MANILA Topographic Map. Sheet No. P.C.G.S. 2511; and Philippine Coast and Geodetic Survey (1982) 1: 250,000 TARLAC Topographic Map. Sheet No. P.C.G.S. 2509.

The southwest monsoon and typhoons annually deliver approximately 2,000 millimetres of rain to the region, but the amounts have been decreasing since 1900 (Intergovernmental Panel on Climate Change, 1995; Jose et al., 1996) and cannot be blamed for the worsening floods. Due to an unfortunate combination of coastal configuration and seasonal wind regime, waves generated during the rainy southwest monsoon also raise tide levels by as much as 80% at the northern end of the bay (Siringan and Ringor, 1998), thus hindering run-off into the bay. Waves three metres high can be generated even along the limited western fetch. Southerly wind speeds at Manila can exceed 220 kilometres per hour (34 metres per second), and waves 3.7 metres high have been recorded at Manila's port (Nippon Koei Co., Inc., 2001). Typhoon winds and waves historically have been so severe in Manila Bay that the US Navy has declared it an unsafe haven during typhoons (Brand et al., 1979). Storm surges occurred seven times from 1960–72 (Philippine Atmospheric, Geophysical and Astronomic Authority, unpublished records).

Also unfortunately, about 70% of the rain arrives between May–June and September–October (Umbal and Rodolfo, 1996). In the flood-plagued areas, surface reservoirs are too small to store enough water for agriculture, fishponds and domestic needs during the dry season. Uncontrolled and unmonitored use of groundwater, already far too heavy, inevitably accelerates as the population grows (Siringan and Rodolfo, 2003).

## Research methods

We have compared sea-level data gathered at Manila's South Harbour with records of groundwater use. Analysis of selected bandwidths sensitive to the presence of water in satellite images taken in 1989 and 2001 shows how the flooding has evolved (Balboa, 2002; Rodolfo and Siringan, 2003). We have established 19 global positioning system (GPS) stations for monitoring subsidence, and are examining sediment cores up to 10.2 metres from 32 stations for evidence of changing environment, but the results of that work are not presented here.

We have gathered regional sociological information through in-depth interviews with key informants and social surveys. Each key informant, a long-time resident and a leader in local government or in civic or religious organisations, provided data on matters such as the locations of emerging water-wells, changes in land use, flooding severity and the height and extent of maximum tides. Our survey questionnaire solicited, from individual households of selected *barangays* (villages), information regarding emerging well pipes, saltwater intrusion, river siltation, flooding history and, in coastal communities, changes in tidal incursion and attendant changes in vegetation and land use. Municipalities were selected in non-coastal areas less prone to flooding, flood-prone non-coastal areas and coastal areas highly susceptible to flooding. From each of two *barangays* representing each municipality, we interviewed three households and one key informant, amounting to a total of 208 people from 53 *barangays*. We also have elicited feedback in numerous meetings and discussions at which we presented and validated our findings.

# Results

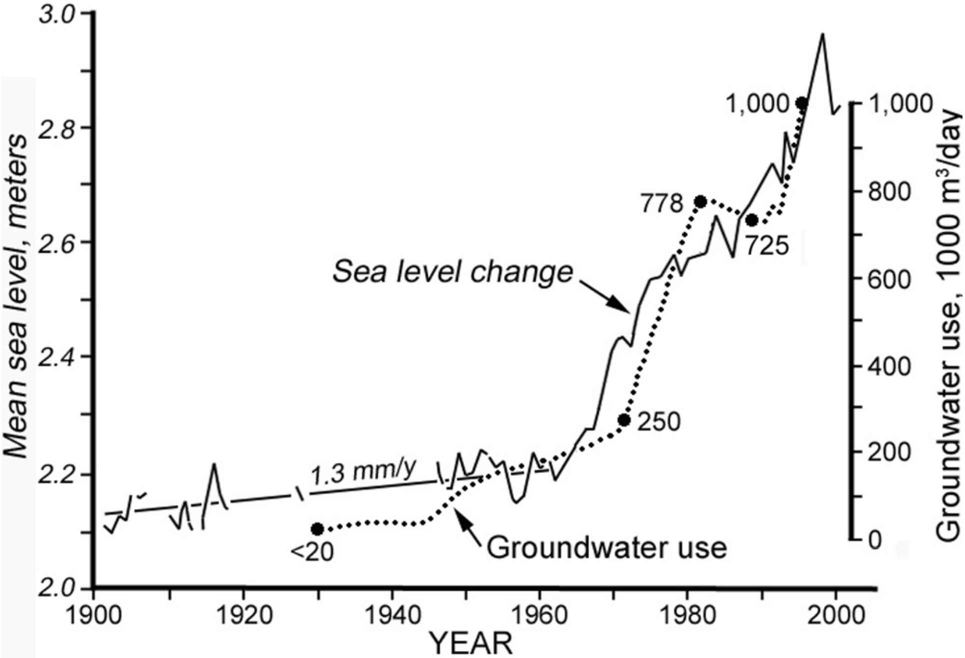
## Metro Manila groundwater use and land subsidence

Sea level has been recorded at Manila's South Harbour since 1902. It rose around 1.3 millimetres per year—the global rate—until the early 1960s, when it increased to about 2.6 centimetres per year (Siringan and Ringor, 1998; Siringan and Rodolfo, 2003). Figure 2 correlates the apparent rise in sea level with the increase in Metro Manila groundwater use until 1995.

## Satellite imagery

Selected electromagnetic bandwidths sensitive to water document how waterlogged areas around the northern bay are evolving and expanding (Balboa, 2002; Siringan and Rodolfo, 2003). Fishpond dikes at the coast continue to be raised in response to rising relative sea level, confining coastal wetlands and subdividing them into smaller ponds. Notably, the areas along the Pasac River, which was contained with dike**s** after the 1991 Pinatubo eruption, are now waterlogged. Without the dikes, floods escaping from the channel would have deposited sediment on the floodplain, counteracting the elevation loss from autocompaction, and compensating in part for anthropogenic subsidence.

**Figure 2** Sea-level rise recorded at Manila's South Harbour from 1902–2000* and groundwater use in Metro Manila over the same period**



**Sources:** * Unpublished records of the Philippine Government's National Mapping and Resource Information Authority; ** Unpublished records of the Philippine Government's Metropolitan Waterworks and Sewerage System.

## Sociological data

Respondents have reported that between 1991 and 2002, the worst annual floods have increased in height by 0.2 to one metre in Bulacan and KAMANAVA, and by 0.3 to one metre in Bataan and Pampanga provinces. Similarly, over that 11-year period, spring-tide heights have increased by 0.3 to two metres. These data indicate subsidence rates ranging from 1.7 8.3 centimetres per year, with more typical values of 2.5 to five centimetres per year. The highest rates were observed around fishpond areas and are comparable to those reported from western Taiwan (Table 1). Direct measurements at water wells that appear to be rising out of the surrounding ground in an area of more than 100 square kilometres north of Pampanga Bay confirm these rates (Siringan and Rodolfo, 2003). The DPWH independently measured similar rates by reoccupying elevation benchmarks established in the 1950s (CITI Engineering Co., Ltd., 2001a).

Currently, even moderate rains flood the more inland Pampanga municipalities, whether or not they are affected by the deposition of Pinatubo sediment. Guagua, parts of Sasmuan and Lubao are inundated for six months of the year, Minalin for almost nine months and Macabebe for three to four weeks. Storm floods also are becoming more frequent and last longer in Bulacan and KAMANAVA.

In coastal communities, typhoons and southwest monsoons used to trigger floods that typically lasted for only around two hours, peaking during high tides. Now, spring tides may take an entire day to subside, and areas that stood above tide levels 30 years ago are frequently flooded by almost one metre. Most coastal Bulacan *barangays* now experience spring tides that take between half a day and one day to subside.

Roads need to be raised regularly in order to keep them navigable during spring tides and heavy rains. We were sceptical about reports that a road in one Lubao *barangay* has to be raised annually by approximately half a metre, until a benchmark established there in 1999 and reoccupied in 2001 confirmed a 46 centimetre per year subsidence rate (Nippon Koie Co., Inc., 2001).

At numerous meetings with local government and non-governmental organisations (NGOs) (Rodolfo et al., in press), we learned how difficult it is to convince local people of the role of subsidence in aggravating the flooding. For many, their ancestral homes and lots are their only assets, and they cannot conceive of leaving. The government is too poor to resettle them elsewhere properly, 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.

Some people are reluctant to recognise that their own prodigal use of groundwater contributes to subsidence and the consequent flooding. Furthermore, the heavy seasonal rains leave the mistaken impression that the exceedingly abundant water must be recharging the ground below, no matter how much is withdrawn. Part of the difficulty lies in the fact that the process is hidden; it is much easier to blame flooding on visible causes such as fishponds and slums encroaching on estuaries, and the choking of drainages by water hyacinths and garbage. Some people have learned about the ramifications of their excessive groundwater use but, denied alternative sources, have resigned themselves to the worsening situation. Many acknowledge that free-flowing artesian wells must aggravate subsidence, but fear that temporarily closing a well might result in it drying up or make the water dirty. 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, stopgap solutions. Optimism is rampant during the flood-free half of the year, when people want to forget the wet and discomfort.

## Discussion

### The role of agriculture and fishponds

Rice, by far the biggest crop north of Manila Bay and across East Asia, consumes more water than any other crop, and the 'green revolution' hybrids use proportionately more than traditional varieties (Pearce, 2004). To mitigate drought during El Niño episodes, the Department of Agriculture provides shallow wells to farmers, according to the former Director of its Bureau of Agricultural Research, E.R. Ponce,[3] thus aggravating subsidence.

Fishponds make enormous demands on their environments (Chua, 1992). Around Manila Bay, subsidence begins when ponds are first diked and dried. This rapidly dewaters the upper few metres of sediment, which, having the greatest porosity and water content, also can shrink the most. Nutrient sources, such as chicken manure, are introduced to support algae before filling the ponds and then before every annual restocking. Rotting excess algae effectively poisons the pond water, which is flushed into the sea—deteriorating the environment of free-living species—and is replaced with great quantities of river or groundwater. Flooding is also enhanced by illegal expansion of fishponds into tidal channels (unpublished DPWH data). Privately owned golf courses and swimming pools also are maintained with large, unregulated volumes of groundwater.

Domestic groundwater use may not cause the most subsidence. People complain that their wells stop flowing when high-volume pumps of large plantations or fishponds are active. Some of the most elusive and crucially lacking data are the rates and volumes extracted, because operators do not allow their measurement. Proper assessment and regulation would require government action, backed by court injunctions and troops, if necessary.

### Declining population growth

From 1990–2000, the Philippine population grew by 26%, to 76.5 million (National Statistics Commission, 2000). Philippine coastal plains are where farming and aquaculture are most extensive, where 63% of Filipinos live and where population growth is most rapid; however, populations in the study area are increasing more slowly than in the country as a whole, possibly due in part to deteriorating quality of life. The regional growth rate in this area rose more rapidly than in the entire nation from 1990–95, but was cut by more than one-half between 1995 and 2000 (Table 2) (National

**Table 2** Population changes in the coastal/estuarine areas bordering northern Manila Bay

| PROVINCE/town | 1990 | 1995 | 2000 | Percentage growth | |
|---|---|---|---|---|---|
| | | | | 1990–95 | 1995–2000 |
| BATAAN | 425,803 | 491,459 | 557,559 | 15.42 | 13.4 |
| Orani | 43,494 | 48,695 | 52,501 | 12.0 | 7.8 |
| Samal | 21,991 | 24,560 | 27,410 | 11.7 | 11.6 |
| *Flood-prone Bataan* | *65,485* | *73,255* | *79,911* | *12.0* | *9.1* |
| BULACAN | 1,464,137 | 1,784,441 | 2,234,088 | 21.8 | 25.2 |
| Hagonoy | 90,212 | 99,423 | 111,425 | 10.2 | 12.1 |
| Malolos | 125,178 | 147,414 | 175,291 | 17.8 | 18.9 |
| Obando | 46,346 | 51,488 | 52,906 | 11.1 | 2.8 |
| San Miguel | 91,124 | 108,147 | 123,824 | 18.7 | 14.5 |
| San Rafeal | 49,528 | 58,387 | 69,770 | 17.9 | 19.5 |
| *Flood-prone Bulacan* | *352,860* | *406,472* | *463,446* | *15.2* | *14.0* |
| PAMPANGA | 1,295,929 | 1,635,767 | 1,882,730 | 26.22 | 16.4 |
| Candaba | 68,145 | 77,546 | 86,066 | 13.8 | 11.0 |
| Guagua | 88,290 | 95,363 | 97,632 | 8.0 | 2.4 |
| Lubao | 99,705 | 109,667 | 125,699 | 10.0 | 14.6 |
| Macabebe | 55,505 | 59,469 | 65,346 | 7.1 | 9.9 |
| Masantol | 41,964 | 45,326 | 48,120 | 8.0 | 6.2 |
| Minalin | 34,795 | 35,670 | 35,150 | 2.5 | -1.5 |
| San Fernando | 157,851 | 193,025 | 221,857 | 22.3 | 14.9 |
| Sto. Tomas | 33,309 | 29,628 | 32,695 | -11.1 | 10.4 |
| Sasmuan | 21,148 | 23,146 | 23,359 | 9.4 | 0.9 |
| *Flood-prone Pampanga* | *600,712* | *668,840* | *735,924* | *11.3* | *10.0* |
| KAMANAVA | 1,571,148 | 2,036,847 | 2,232,295 | 29.6 | 9.6 |
| Kaloocan City | 763,415 | 1,023,159 | 1,177,604 | 34.0 | 15.1 |
| Malabon | 280,027 | 347,484 | 338,855 | 24.1 | -2.5 |
| Navotas | 187,479 | 229,039 | 230,403 | 22.2 | 0.6 |
| Valenzuela City | 340,227 | 437,165 | 485,433 | 28.5 | 11.0 |

**Note:** Data for each province refer to its entire population.

Statistics Commission, 1990; 1995; 2000). In fact, populations of Minalin town in Pampanga and Malabon City in KAMANAVA have actually declined.

The proximity of Bulacan to Manila is largely responsible for the extremely rapid growth of its coastal population: 21.8% from 1990–95, and 25.2% from 1995–2000. Most of this growth is in higher areas away from the coast, and in a few areas raised by landfill. Strikingly, the town of Obando, notoriously flood-prone and frequently invaded by tides, lagged far behind all of the other Bulacan municipalities, growing only 14.2% from 1990–2000, and only 2.8 percent over the last five years of that period.

Between 1995 and 2000, population growth in KAMANAVA lagged behind Bulacan mainly because Malabon lost people and Navotas experienced only negligible growth. Those two suburbs are the most flooded by rainstorms and high tides. The adjacent cities of Kalookan and Valenzuela are more inland and on somewhat higher ground, but also experienced sharp declines in growth.

## Governmental responses

The national Department of Agriculture funded some of our research in 2001 because it sought to anticipate and adjust to rising regional sea level, but that support was curtailed after its first year because of budgetary difficulties. Intra-governmental communication and coordination leave much to be desired. National and local government responses have been disappointing. Indeed, local politicians create myriad wells to woo and reward voters. Driven by the three- and six-year election cycles, government efforts favour short-term contingencies over efficacy, and are largely ‘palliative’—soothing the anxious public with projects that accomplish little. Thus, citing government records, Orejas (2002a) complained that none of the flood-control projects beginning in 1938 has eased flooding in Bulacan and Pampanga.

Strong attachment to place makes many people, especially the poor, eager to believe that engineering measures will free them from floods. Coupled with the strong public clamour for engineering solutions, the great potential for illegal profit inevitably leads to large flood-control projects, regardless of their efficacy. Government corruption is widely recognised. In the latest Corruption Perception Index (Transparency International, 2004), which assigned each of 145 countries a rating between 10 (least corrupt) and one (most corrupt), the Philippines scored 2.6. At an international conference in Seoul, South Korea in 1999, two years before a public uprising ousted President Joseph Estrada of the Philippines for his own alleged venality, he declared that Philippine government project funds routinely lose 20% to graft and corruption (Marfil, 1999). That figure is over and above the 10% that Philippine law allows congressional project proponents to claim as finders’ fees. This level of corruption was already in force before the Pinatubo eruption, which, together with its decade-long aftermath of destructive lahars, lent an air of crisis and imminent danger that provided the excuse for not conducting appropriate feasibility studies before construction (Rodolfo, 1995). Little effort was expended to determine the properties and behaviour 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 funding and quality were built, failed, and were rebuilt, either in original form or with token design improvements, only to fail again. Nevertheless, funds continue to be appropriated for their repair (Orejas, 2002b).

The lahar threat has diminished, but the practice continues in expensive, inutile flood-control projects. Being impoverished, the government must borrow funding. Loans, primarily from the Japanese Bank for International Cooperation (JBIC), have attractively low interest rates, but stipulate the use of expensive Japanese contractors, engineering consultants and materials. Filipino scientists and engineers are not consulted, and even the Secretary of the DPWH has complained publicly about not being kept abreast of plans: 'More often than not, the Japanese contractors and consultants do not give us complete documentation for the projects, resulting in delays in implementation' (Nocum, 2003).

## Guagua River project

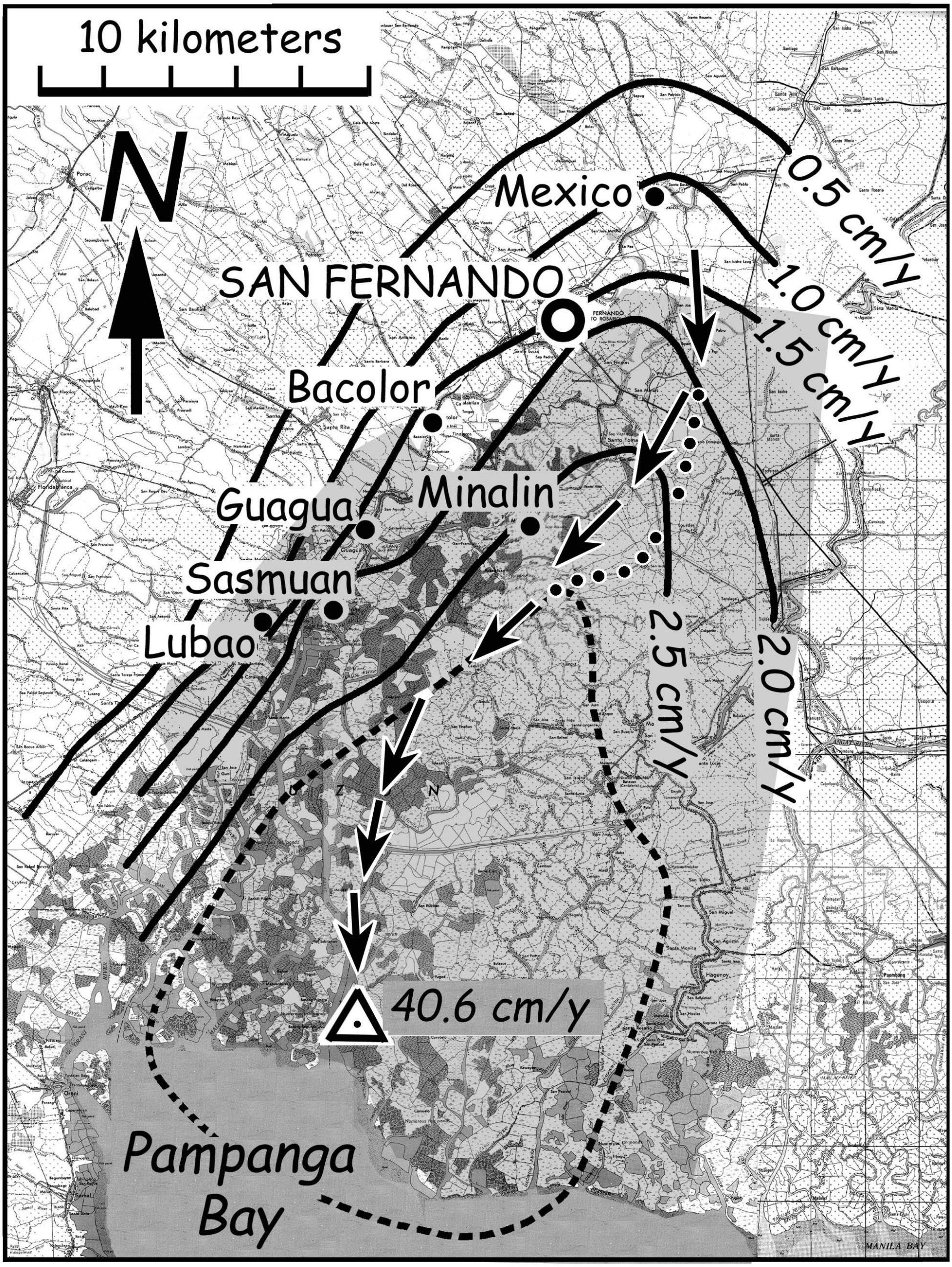
Government officials with little technical background cannot judge the efficacy of flood-control projects. The extent to which basic science is ignored by engineers and consultants is exemplified by a DPWH dredging project, costing approximately USD 9 million, that is meant to alleviate flooding in the Pampanga municipalities of Guagua and Lubao (Nippon Koie Co., Inc., 2001; undated DPWH brochure circulated since 2003 entitled 'Pinatubo Hazard Urgent Mitigation Project'). Of the 12 kilometres of channel to be deepened, the lower 10 kilometres is entirely below mean lower-low water and thus almost always below sea level. The configuration of the submarine channel floor is characterised in the plans as a 'slope affected by tides'. There is no slope; besides, what governs channel flow is the slope of the water surface, not that of the bottom. Dredging below sea level can only facilitate the flow of incoming and ebbing seawater.

## Third River project

Plans for another project worth over USD 61 million (DPWH, 2003) present subsidence data, but ignore their implications for flooding. Figure 3 illustrates how the 'Third River' dredging channel, which joins segments of pre-existing estuaries, was routed almost axially within the area of fastest subsidence that the Japanese and other foreign consultants measured and contoured. It is also centrally located in the area that another of their maps defined as most deeply flooded during maximum spring tides (Nippon Koei Co., Inc., 2001, Figures. 2.11 and 2.12). The project was approved and initiated long before Filipino scientists outside of the DPWH learned of such details.

The most benign interpretation of why the channel was thus situated precisely where it would be least effective is that this site is the only one for which the landowners would offer permission. Local authorities often complain that the national government does not consult them sufficiently in planning (Rodolfo, 1995) and frequently does not remunerate the owners of property it expropriates by power of eminent domain (cf. Lacuarta, 1993, for example). Right-of-way owners resist, and political

**Figure 3** The Third River flood control project in Pampanga Province



**Note:** As diagrammed in Figures 2.9, 2.10, 2.11 and 2.12 of Nippon Koie Co., Inc., 2001. The isopleths of subsidence rates in millimetres, re-expressed in centimetres per year, were traced from Figure 2.11. The closed dashed isopleth is not labelled. The subsidence rate of 40.6 centimetres per year is from Benchmark BMS6 located on Figure 2.9. It is derived from the DPWH elevations of 2.630 and 1.818 metres above sea level measured in 1999 and 2001, respectively, both given in Figure 2.10. The shaded land area is from Figure 2.12, 'Schematic of Inundated Area of Pasac Delta During Maximum Tide of 2.1m'. The extent of this flooding does not take into account any additional water rise from rain or wind.

pressures come to bear. The project route was initially the one marked as arrows in Figure 3. It encountered public demonstrations by outraged citizenry (Cervantes, 2001; Orejas, 2001a) and an angry legislator (Orejas, 2001b). The route was changed (Orejas, 2002b) to the dotted line in the figure, which is even more flood-prone than the original course. Landowners are least reluctant to lose land that has already been devalued by flooding and tidal invasion.

Lengthening the channel to skirt recalcitrant landowners decreased its slope, and consequently could only diminish its efficacy. Nevertheless, the project continues, at a cost of 3.4 billion pesos, or some USD 68 million (DPWH, 2003, unpublished report).

## KAMANAVA flood control project

The engineering project that elicits our greatest concern is designed to protect KAMANAVA from both rainstorm and tidal flooding through the use of dikes, river walls, flood-control gates and pumps. Funded with a Japanese loan of five billion pesos, about USD 90 million, the project includes an 8.6-kilometre polder dike, composed only of earth, to enclose and protect the Malabon and Navotas areas that are already at or below mean sea level. A recurrence of the 1.93-metre spring tide, the highest on record (Siringan and Rodolfo, 2003), would leave the polder dike with only 10 centimetres of freeboard. In Manila Bay, wave set-up can raise tide levels by as much as 80% (Siringan and Ringor, 1998). The dike's height of two metres was justified by an analysis that yielded storm-wave heights of only one metre. The modellers misread the bay depths charted in metres as given in fathoms (1.83 metres), and used wind speeds of only 40 kilometres per hour—those of a mere tropical depression (Citi Engineering Co., Ltd., 2001b, pp. C-17–C-18).

The designers plan to pump floodwaters out of the polder during low tides, but sustained southerly winds can raise sea level significantly for days, rendering the structure ineffective. Even discounting storm waves, surges driven by typhoon winds can raise sea level to overtop this height. Brand et al. (1979) and Nimes and Baldonado (2000) list storm surges that occurred in Manila Bay in 1960, 1964, 1965, 1970, 1971 and 1972. Two of these surges parked large ocean-going ships on Manila's coastal boulevard.

The designers acknowledged that groundwater use between 1965 and 1990 has caused 2.72 centimetres per year of subsidence (Citi Engineering Co., Ltd., 2001a). That figure is already too low, yet they incorporated only 0.65 centimetres per year into the design, depreciating the implications of continuing subsidence for future maintenance. In 10 years or less, portions of the dike could subside one metre, and founder.

Quite possibly, the project exacerbates the danger posed by floods by giving the endangered people an undeserved sense of security. A stated DPWH justification for the project is to attract additional people and industries to settle within the polder. In Malabon and Navotas, more than 500,000 people already are at risk (Table 2); the project would increase that number.

Subsidence and aggravated flooding from groundwater overuse share the root cause of many other Philippine problems. Along with increasing deforestation, soil erosion and lethal landslides, garbage, over-crowded classrooms, joblessness and, to the detriment of the Filipino family, the country's increasing economic reliance on overseas workers, it stems from rapid population growth, with no consistent governmental policy to moderate it since 1969 (Acoseba, 2003a). From 1995–2000, the national population grew annually by 2.36% (National Statistics Commission, 2000). A formal Population Management Program, created by the government's Commission on Population to develop measures for decreasing this growth, reported in a press release published in three parts (Acoseba, 2003a; 2003b; 2003c) that its recommendations were embodied in a Reproductive Health Care congressional bill. Largely because of concerns about abortion and contraception, that bill languished in committee for two years. It was supposed to be the prelude to a proposed Population and Development Act, but the president threatened to veto it in 2003 and offered no alternative means for managing population growth. In 2005, a Responsible Parenthood and Population Management Act was still undergoing hearings (Mendiola, 2005).

## Conclusions and recommendations

### Reducing groundwater usage

To curtail subsidence, two measures must be implemented. First, it would be slowed by any replacement of groundwater with surface sources. The region is bordered by mountains on which small dams could be built to store water in surface and underground reservoirs. Families and small groups of farmers in developing countries use many simple rain harvesting techniques (Pearce, 2004) that merit attention, including building low ridges to impede run-off and encourage infiltration, and restoring wetlands to their natural hydrologic roles. At the family level in other places like Bermuda, the roof of every house is built to funnel all rainwater into cisterns.

To advise decision-makers properly about sustainable groundwater use, scientists would have to acquire the various data already being gathered in neighbouring countries, as described above in the sub-section on control. Synoptic microtopographic data are gathered most easily by radar interferometry. Rates of recharge are needed if appropriate limits are to be placed on pumpage. This in turn requires detailed stratigraphy and geotechnical analysis of the complex deltaic deposits, and data that specify where and at what rates groundwater is pumped. Given that excessive pumping may affect water quality, chemical analyses are also necessary.

Second, if groundwater is to continue to be exploited, it must be regulated. A Water Code was promulgated decades ago (*Water Code and the Implementing Rules and Regulations,* 1979), but the requirements are ignored, beginning with the first one: drilling permits, which dictate that pump users must consider the possibility of 'groundwater mining'—extracting more than nature recharges—and its other bad consequences besides land subsidence. 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 metres. The sediments near the surface are the most waterlogged and the most easily dewatered and compacted, and shallow wells are great in number.

Wells should be limited to a small, enforceable number, run and regulated by local governments. People would have to pay for piped water, but this would engender respect for it, and its conservation. Bangkok was able to reduce its subsidence from between five and 10 centimetres per year to approximately two centimetres per year because the principal wells were industrial. New taxes on groundwater made imported surface water cheaper (*Bangkok State of the Environment,* 2001). In a just world, efficient regulation would begin with the most prolific and wasteful users.

People should be encouraged and exhorted to conserve groundwater, and empowered to do so. For example, there is some justification for the fear that flow may be soiled or permanently lost if artesian wells are shut down temporarily. Wells equipped with gravel packs avoid those problems (Driscoll, 1986), and research might 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 and difficult to implement. The nation must stop using waterways as garbage dumps and housing sites. Original channel widths must be restored where illegally choked by fishponds. Floodwaters should be allowed to occupy their floodplains. Mountain reforestation reduces and delays run-off, increases groundwater recharge and diminishes upland erosion and siltation in lowland channels. Furthermore, if the flood run-off from the uplands is carrying less sediment than it can transport as it arrives at the lowland channels, it will erode and unclog them. If any of these measures are to be effective, national coordination is essential because watersheds and underlying aquifers cross political boundaries.

The Philippine population, mostly residing on coastal plains, is squeezed, figuratively, between the two jaws of a vice: its own rapid growth, and the subsidence and flooding generated by its own use of groundwater. We may take little comfort in the realisation that, although subsidence is accelerating, it must stop eventually, even without proper regulation. As groundwater continues to be mined, subsidence, tidal incursion and storm flooding can only get worse. In due course, however, the groundwater may be so depleted or contaminated by intruding saltwater that its use will stop; or 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 occurred will be permanent, and the sooner this is recognised, the sooner ameliorative steps can be taken.

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[2] See appropriate references listed in Table 1.

[3] Personal communication, 2002.

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