Adapting to Climate Change in Shanghai and the Yangtze Delta Region

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Summary: China’s Yangtze Delta Region (YDR), anchored on Shanghai, is the most important regional economy in the country. It is also one of the most exposed in the world to severe weather events. Probable changes in climate extremes and means include growing frequency and intensity of cyclones and storm surges, heatwaves, worsening metropolitan heat island effects, and sea level rise that could decelerate flows from the Yangtze and along 10,000 km of waterways that are already heavily polluted. Constraints to effective adaptation planning include the bifurcation of governance between urban and suburban districts and inadequate coordination and cooperation among 75 sub-national governments in the Delta. However, recent institutional reforms at the national and provincial levels present a timely opportunity for a new effort at preparing an adaptation strategy to mitigate impacts on the 80 million people living in China’s economic powerhouse.

Key Words: metropolitan region, megalopolis, institutional constraints, regional governance, metropolitan governance
I. INTRODUCTION
China’s Yangtze Delta Region (YDR), anchored on Shanghai, is the country’s largest and most prosperous economic area. Its coastal location, geographic characteristics, and recent development trends make the YDR one of the most exposed – and perhaps vulnerable – regions in the world to severe weather events projected to emerge from climate change. How well Shanghai and the other metropolitan regions in the YDR adapt to climate change will influence not only the safety, health, and quality of life of their residents, but also the region’s productivity and China’s global competitiveness.

Like many other large metropolitan regions around the world, multiple jurisdictions, gaps in mandates, and inconsistent coordination among governments compound the challenges in designing, implementing, and monitoring a regional adaptation strategy for the YDR. However, unlike in many other countries, an incipient institutional framework and instruments of governance exist nationally and in the region on which an integrated adaptation strategy could be systematically constructed, applied, and monitored, given the political will and resources. Such a strategy could potentially become a global adaptation model for other metropolitan regions comprised of multiple jurisdictions that are facing severe climate change impacts.

This paper describes some of the key recent development trends in Shanghai and YDR, tentative observations on the region’s exposure to severe climate events, potential impacts if trends continue, institutional constraints to the preparation and implementation of effective adaptation strategies, and recent experiments in governance that could be harnessed to overcome these constraints.

II. RECENT DEVELOPMENT TRENDS
1. Urbanization of the Yangtze Delta Region
China’s State Council defines the Yangtze Delta Region as comprising Shanghai Municipality and 15 Prefecture-level Cities, stretching from Nanjing in the north through Changzhou, Wuxi,
Suzhou to Shanghai, and south-westwards through Hangzhou to Shaoxing, Ningbo and as far south as Taizhou (Fig. 1). This territory held almost 83 million people in 2004 across an area of 109,647 km². We define a smaller functional territory within the YDR of 80,000 km², comprising a dense corridor of cities, towns and villages holding 77 million people stretching from Nanjing to Ningbo (Fig. 2). The axis of this corridor exhibits many of the characteristics of a megalopolis.

Figure 1: Shanghai and 15 Prefecture-level Cities in the Yangtze Delta Region

Source: Chreod
Note: shaded area represents a two-hour drive time from central Shanghai in 2009.

4 In comparison, the Republic of Korea covers an area of 99,000 km², and holds a population of 49 million. The YDR’s population density is slightly more than twice that of Japan, three times the overall density of the UK, 2.8 times the density of Vietnam, four times that of the State of New York, and nine times the density of California.

5 This corridor was defined by: 1) mapping on GIS as points all Street Committees, Towns, and Townships in the YDR; 2) calculating population densities in a 6 km² radius (using kernel densities on GIS) using total population figures for each point from the 2000 National Census (including migrants resident longer than six months); 3) plotting uninhabitable spaces in the YDR on GIS (water bodies, floodplains, slopes greater than 8°; and 4) plotting all roads in the YDR as of 2007.

6 See Leman (2002) for earlier definitions of the YDMG.
Although holding only 6.3% of China’s registered population, the YDR plays a pivotal role in the country’s economy – a role that has grown significantly over the last two decades (Fig. 3). Since 1990 the YDR has gained almost an 8% share of China’s Gross Domestic Product (GDP), accounting for 23% of national production in 2007. Economic growth has attracted more than 18 million migrants to new jobs in the YDR: according to the 2000 National Census, migrants comprised 20% of the Delta’s total population in 2000, a proportion that has likely grown significantly in recent years.

Annual GDP growth for the YDR as a whole averaged 13.7% from 1997 to 2005, making the region one of the fastest growing regional economies in global history.\(^7\) Gross Domestic Product in all PLCs grew at more than 10% during this period, with most hovering between 11–14%. Shanghai’s growth was in the middle range at 13.3%. Suzhou, reaping agglomeration benefits from adjacent Shanghai, grew at the highest rate, 17.2%, more than 3% points higher than third-ranked Hangzhou, and well ahead of neighbouring Wuxi and Nanjing to the north. More importantly, Suzhou’s rapid growth consolidated its position as the YDR’s second largest PLC-

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\(^7\) When compared to historical national growth rates in Maddison (2006).
level economy. After Shanghai, which accounted for 27%, Suzhou produced 12% of the YDR’s GDP in 2005 compared with 9.3% in 1997.

A fundamental change appears to be occurring in the YDR as metropolitan regions develop comparative advantages in what has gradually become a market economy since the early 1990s. Once China’s main base of heavy industry, Shanghai has closed down antiquated factories in its urban area over the last 20 years, and relocated remaining industries to suburbs and farther afield in the YDR. Shanghai is transforming into a producer services and shipping hub; restructured industries are becoming higher value-added (e.g. ICT, automotive and chemicals). Urban areas in the YDR close to Shanghai have taken on the bulk of medium value-added manufacturing. Suzhou and Kunshan, immediately adjacent to Shanghai along the megalopolitan corridor, are becoming the Delta’s principal manufacturing powerhouse, reaping agglomeration benefits from Shanghai, including a growing range of sophisticated producer services and logistics infrastructure (Fig. 4).

Experience in other countries suggests that this spatial trend will continue: industries will become more dispersed along the megalopolitan corridor, and core cities will specialize in producer and consumer services. This trend has major implications for a regional climate change adaptation strategy: 1) differences in urban economies, incomes, and lifestyles will continue to widen and, with them, vulnerability to climate changes; 2) adaptation measures will therefore need to vary, perhaps considerably, to accommodate these differences; 3) despite spatial dispersion, high densities of populations and firms – and high and growing linkages between them – mean that adaptation must be structured at the regional scale; and 4) given the rapid pace of change in the megalopolis, predicting spatial patterns and characteristics of continued development will require accurate, comparable, regularly-updated and shared information if
adaptation measures are to be adequately planned, financed, and implemented.\(^8\)

![Figure 4: Manufacturing Dynamics in the Yangtze Delta Region, 1997 – 2005](image)

*Source: calculated from Provincial Statistical Yearbooks, 2006, 1998
Note: data are for Prefecture-level Cities and Shanghai Municipality as a whole; GDPS is GDP from secondary sector*

2. **Shanghai’s Emergence as a Global Metropolis**

With a population of just under 20 million, Shanghai will be the fourth largest metropolitan region in the world by 2010, behind Mumbai, Seoul, and Tokyo\(^9\) (Fig. 5). Although local birth

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\(^8\) The Global City Indicators Facility (<www.cityindicators.org>), supported by the World Bank, might eventually consider adding adaptation indicators.

\(^9\) The population estimates for 2010 are from Chreod’s World Metropolitan Region database (first iteration was completed in March 2009). While the UN Population Division’s World Urbanization Prospects (2007 edition) reports populations at the scale of ‘urban agglomerations,’ these are defined varies across countries. For example, the UN’s database seriously under-reports actual populations for Chinese cities. Chreod has therefore constructed a database of populations in 2000 and 2010 for all of the world’s metropolitan regions with 2010 populations over 1 million from: 1) Chreod’s China Metropolitan Region database (described in Leman, 2005); 2) US Bureau of the Census 2008 population estimates for Metropolitan Statistical Areas; 3) similar estimates from Statistics Canada for Canada’s cities; 4) Eurostat’s 2004 estimates of population in ‘Larger Urban Zones’ for all of Europe and Turkey; and 4) UN World Urbanization Prospects (2007) estimates for all other countries. Estimates for selected metropolitan regions (e.g. Seoul and Johannesburg) are from national statistical agencies. This database will be continually developed and fine-tuned to attempt to provide consistent and comparable ways of reporting populations of metropolitan territories as functional regions.
rates are declining, and registered residents are aging rapidly, Shanghai’s population continues to grow. The metropolis has become a strong magnet for migrants from other parts of China, ranging from semi-skilled construction workers to workers in retail, manufacturing, and financial and producer services. Given the size and range of employment opportunities, Shanghai will continue to attract significant numbers of migrants well into the next decade. We have recently completed projections of Shanghai’s population to 2030, in five-year increments, using two approaches: demographic, including migrants; and labour force requirements. Both approaches project Shanghai’s population to grow from 19,127,000 in 2008 to 24,500,000 by 2020 and approximately 27,000,000 by 2030 (Fig. 6).

Market reforms and unprecedented levels of investment in infrastructure since the early 1990s have unleashed huge agglomeration effects arising from Shanghai’s size and density. In 2007, PriceWaterhouseCoopers (PWC) projected the size of the economies of the world’s largest metropolitan regions to 2020 (PWC, 2007). In 2005, Shanghai ranked 32nd in the world (Fig. 7). By 2020, Shanghai’s rank improves to 16th. Shanghai will likely become the third largest metropolitan region in Asia and the 16th largest global metropolitan economy by 2020.

With the support of State Council, the Municipal Government has been attempting, since the early 1990s, to transform Shanghai into a ‘global metropolis’. Its Eleventh Five-Year Plan (2006–2010) articulates the following vision:

According to the Central Government’s development orientation for Shanghai, Shanghai will have been substantially turned into one of the international economic, financial, trading and shipping centers, and a socialist modern international metropolis by the year 2020. According to the requirements of the State, Shanghai will make the efforts to enhance its international competitiveness as the main theme of development for the next five years and as a continuation of the theme of the Tenth Five-Year Plan to enhance the overall competitiveness of the city in the new era. The efforts will center on the goals of developing the Four Centers (an international economic center, an international financial center, an international trading center, and an international shipping center), and a socialist modern international metropolis, and represent the common aspiration of all the people of Shanghai to seize opportunities to achieve fast and sound development.

Beyond the somewhat lofty rhetoric, Shanghai has undergone a remarkable transformation over the last 20 years, from an economically stagnant industrial behemoth to one of the most vibrant cities in Asia. The basic outlines of a trajectory have been set, pointing to Shanghai’s potential evolution over the next decade or so into a globally-significant center of finance, trade, innovation-based manufacturing, and culture, and the core hub of a rapidly-urbanizing Yangtze Delta Region. In global terms, Shanghai could well join the ranks of the world’s top 10 metropolitan economies in the next 20 years. Among the many constraints that Shanghai will need to overcome to become a truly global metropolis, climate change looms as a challenge of as yet undefined scale, severity, and urgency.11

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10 These projections were prepared in 2008 for the World Bank’s Task Team prior to appraisal of the third tranche of the Shanghai Environment Adaptable Program Loan (Chreod, 2008).

11 Extensive scientific research on climate change is underway in China in many institutes and universities. Much of the research focuses on climatic modeling, analysis of historic weather patterns, and oceanographic and limnological aspects, and not on social, economic, and fiscal impacts. Adaptation is touched upon, but mostly in terms of flood-control engineering. Research is essentially lodged in the natural sciences and engineering – based on the available literature, there is little apparent interdisciplinary research on climate change impacts involving social scientists.
Figure 5: Populations of World’s 40 Largest Metropolitan Regions, 2010 (1000s, est.)
Source: Chreod World Metropolitan Regions database
Note: red bars represent metropolitan regions in the Yangtze Delta Region; blue bars represent metropolitan regions elsewhere in China.
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Figure 6: Projected Population of Shanghai to 2030
Source: Chreod (2008)

Figure 7: Ranking of 50 Largest Metropolitan Economies, 2005 and 2020 (GDP US$ billion, PPP)
Source: PriceWaterhouseCoopers (2007)
III. EXPOSURE TO CLIMATE-RELATED RISKS

1. Global Context

We are developing methodology for assessing the vulnerability of the world’s 444 metropolitan regions to impacts of climate change. At this early point in our work, we have focused on understanding historical exposure to severe weather events to create a baseline for comparing climate change impacts once global prediction data at the local/regional scale become available. Four major impacts of climate change are expected: 1) floods; 2) wind damage and storm surge from hurricanes and cyclones; 3) landslides caused by heavy rains; and 4) drought. Recent historical data on the frequency and intensity of these four types of events were obtained and analysed by Columbia University’s Center for Hazards and Risk Research for the World Bank, in preparation of the “Natural Disaster Hotspots: A Global Risk Analysis” project which ended in 2005 (Dilley et al, 2005). Events were classified in deciles of frequency and intensity using: 1) data on more than 1,600 storm tracks from 1980–2000, assembled by the UNEP/GRID-Geneva Project of Risk Evaluation; 2) for drought, monthly average precipitation data from 1980–2000 to assess the degree of precipitation deficit using the Weighted Anomaly of Standardized Precipitation process developed by the International Research Institute for Climate and Society at Columbia University; 3) for floods, data on extreme flood events from 1985–2003, compiled and geo-referenced by the Dartmouth Flood Observatory; and 4) for landslides, a global landslide hazard map, at a very small spatial scale, prepared by the Norwegian Geological Institute and UNEP Grid-Geneva for the Bank’s Natural Disaster Hotspots project.13

All of these data sets are geo-referenced and therefore could be spatially correlated with our World Metropolitan Regions database. We took the top four deciles for each event and attached decile values for each event type to each of the 444 metropolitan regions using GIS. The (for now) unweighted sum of these four sets of deciles creates an initial Composite Exposure Index (CEI)14 which is mapped globally in Figure 8 and for East Asia in Figure 9.

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12 SRTM Digital Elevation Models were considered as proxies for flood risk, but we decided are too crude at the micro scale since vertical resolutions range from 10–16 meters. For example, in the case of the Yangtze Delta, most areas are under 10 meters in elevation.

13 The landslides data do not differentiate areas at risk from earthquake-induced landslides, and landslides caused by precipitation. In the end, only 3 of the 444 metropolitan regions were in the top four deciles of landslide risk.

14 Two critical climate-related parameters are not yet included in the Composite Exposure Index: extreme temperature events, and vulnerability of coastlines to sea-level rise. We are currently reviewing how to integrate parts of the DIVA database from the DINAS-COAST project into the historical Composite Exposure Index, and possible sources of geo-referenced historical data on surface-air temperature abnormality.
The six most exposed metropolitan regions in the Yangtze Delta Region are shown in red on the scatterplot diagram of population size and values of CEI in Figure 10. Ningbo (CEI of 19) and Taizhou (CEI of 18) are the most exposed, largely due to the frequency of cyclones that
historically land along the coast of Zhejiang Province. Wuxi and Suzhou, located inland, have the lowest CEIs among the YDR’s metropolitan regions, but both are at 15 as they have high exposure to flooding and some exposure to typhoons. Hangzhou has a CEI of 16, and Shanghai is slightly higher at 17. Shanghai is in the 9th decile for cyclones, and in the 8th decile for floods.

The scatterplot clearly shows that all of the metropolitan regions along China’s coast south of the Yangtze River are very exposed to extreme weather events, largely floods and typhoons. Both are expected to grow in intensity and frequency over the next few decades.

What is known about the vulnerability of the Yangtze Delta Region and Shanghai to climate change risks? There is a disparate, seemingly unconnected body of literature in both Chinese and English on various aspects of possible effects (exposure) and impacts (vulnerability) of climate change but, to our knowledge, no integrated risk assessment covering either spatial scale has yet been conducted. Based on our reading of available reports, and the Intergovernmental Panel on Climate Change (IPCC) report (Volume 2) entitled *Impacts, Adaptation and Vulnerability*, we tentatively outline the effects and potential impacts of “changes in extremes” (following IPCC, 2007: 375) in Figure 11 and of “changes in means” in Figure 12. We emphasize that this assessment is very preliminary: there is insufficient correlated information available to reliably estimate the probability of changes, consequences, and vulnerabilities as has
been done in some other parts of the world (for example, recently for London (Greater London Authority, 2008)).

We classify potential impacts spatially in three ways: 1) predominantly localized impacts; 2) impacts across a metropolitan region as a whole; and 3) impacts that are likely to affect most or all of the Yangtze Delta Region.

![Diagram showing potential impacts and their spatial scales]

Figure 11: Likely Effects and Potential Impacts of Changes in Extremes in Shanghai and the Yangtze Delta Region
Figure 12: Likely Effects and Potential Impacts of Changes in Means in Shanghai and the Yangtze Delta Region

2. Changes in Extremes

Extreme events, especially tropical cyclones, storm surges (exacerbated by sea level rise), and heat waves, appear to be increasing in frequency and intensity in the YDR.

Cyclones: Tropical cyclones and associated storm surges along China’s southern coast have killed over 25,000 people since 1950 and incurred huge economic losses (Fan, 2006). The
number of extreme storm surges has grown significantly over the last three decades. Modeling conducted more than a decade ago of surges from five of the worst cyclones to hit the Zhejiang coastline found that a surge of 7.5 meters would hit Shanghai’s southern coast if the most intense cyclone landed at the city directly at high tide in 2050 (Duan et al., 1998). That modeling was based on global sea-level rise (SLR) estimates of 5, 11, and 20 cm for the years 2010, 2030, and 2050: more current estimates are for a 50–70 cm SLR by 2050 for the Yangtze Delta (Fan, 2006).

<table>
<thead>
<tr>
<th>Period</th>
<th># in NW Pacific</th>
<th># landing in China</th>
<th>landing %</th>
<th># storm surges</th>
<th>probability of disaster</th>
<th># extreme storm surges</th>
<th>deaths</th>
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<td>1950 - 1959</td>
<td>262</td>
<td>97</td>
<td>37.02</td>
<td>15</td>
<td>15.46</td>
<td>1</td>
<td>&gt; 5665</td>
</tr>
<tr>
<td>1960 - 1969</td>
<td>354</td>
<td>97</td>
<td>27.4</td>
<td>23</td>
<td>23.71</td>
<td>3</td>
<td>&gt; 16821</td>
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<tr>
<td>1970 - 1979</td>
<td>332</td>
<td>89</td>
<td>26.81</td>
<td>22</td>
<td>24.72</td>
<td>1</td>
<td>831</td>
</tr>
<tr>
<td>1980 - 1989</td>
<td>324</td>
<td>94</td>
<td>29.01</td>
<td>29</td>
<td>30.85</td>
<td>6</td>
<td>1546</td>
</tr>
<tr>
<td>1990 - 1999</td>
<td>304</td>
<td>86</td>
<td>28.29</td>
<td>39</td>
<td>45.35</td>
<td>7</td>
<td>3292</td>
</tr>
<tr>
<td>2000 - 2004</td>
<td>133</td>
<td>40</td>
<td>30.08</td>
<td>20</td>
<td>30.50</td>
<td>3</td>
<td>237</td>
</tr>
<tr>
<td><strong>total</strong></td>
<td><strong>1709</strong></td>
<td><strong>503</strong></td>
<td><strong>29.43</strong></td>
<td><strong>148</strong></td>
<td><strong>29.42</strong></td>
<td><strong>21</strong></td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Tropical Cyclone and Storm Surge Events in China, 1950–2004

Source: Fan (2006): 54

A recent study by OECD assessed the exposure of 136 port cities around the world to coastal flooding due to storm surges and damage due to high winds: Shanghai ranks third in terms of size of exposed populations (Nicholls, 2008).

A particular issue unique to the YDR is exposure of strategic infrastructure of national importance to cyclones and storm surges. Shanghai is completing construction of a new deepwater port offshore at Yangshan Island. When finished in 2015, Yangshan will be the largest container port in the world. It is connected to Shanghai by a 32 km bridge across Hangzhou Bay. Similarly, the world’s longest sea bridge – stretching 36 km and completed in 2008 – connects Haiyan, just beyond Shanghai’s border, with Cixi City across Hangzhou Bay near Ningbo. These two bridges, and Yangshan Port itself, are in the direct path of historical typhoon tracks. The new Pudong International Airport (253,671 flights were handled in 2007) is located 800 meters from the East China Sea.

In addition to tidal flooding along the coast, storm surges cause localized fluvial flooding from a backwater effect as flows drop and, in some cases, are reversed. Fluvial deceleration will likely exacerbate the already declining assimilative capacities of rivers, canals and lakes in the YDR.

Cyclone and surge events could have major implications for much of the Yangtze Delta Region, well beyond the immediate coastline. Most of the alluvial delta is contained within the Taihu Basin anchored on Taihu Lake upstream from Shanghai (Fig. 13). Covering an area of 36,895km², most of the Basin is below 5m from sea level; the Basin holds 43 million people, 55% of the population of the Yangtze Delta megalopolis. An extensive and intricate network of rivers and canals, built over centuries (including the Grand Canal), extends over 10,000 km. The Basin’s flow is 90% to the Yangtze River and 10% to Hangzhou Bay south of Shanghai. Taihu
Lake is heavily polluted (organics and ammonia) and most is eutrophied due to very high levels of phosphorous. Eutrophication led to algae blooms in April 2007 that threatened water supply to the Wuxi metropolitan region; extreme remedial measures were required to divert 1 billion m$^3$ of Yangtze River water to flush out the lake. A similar algae bloom event occurred in July 1990: treated water supply in Wuxi dropped from 200,000 t/d to 50,000 t/d and 46 water-dependent factories had to suspend production. Pollution in the Taihu Basin is a national concern: State Council included the basin in its 1997 3 Rivers and 3 Lakes national priority pollution control plan, and set stringent targets for pollution reduction. These were not met and State Council again intervened in 2002. To date, very little improvement is evident in a few quality parameters, and most have continued to worsen (Chen, 2005).

In 2004, there were 26 water treatment plants in the Taihu Basin with capacities over 50,000 m$^3$/d: for 14 of them, intakes could only source raw water of below Class III standard, i.e., unsuitable for human consumption (Zhu, 2004). Design of most wastewater treatment infrastructure in the YDR relies on the assimilative effects of waterways to reduce pollution effects from outfalls. Massive amounts of agricultural and urban runoffs are also absorbed by lakes, rivers, and canals. The effects of storm surges – and sea level rise (reviewed below) – on fluvial deceleration in Shanghai and the wider Taihu Basin could have serious episodic impacts throughout the Basin. To our knowledge, these have not yet been modeled, but it is highly likely that water pollution levels will rise throughout the YDR if flows decelerate both from ‘changes in extremes’ and ‘changes in means’.

![Figure 13: Taihu Basin](source: Chreod)

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15 Tenth Five-Year Plan on Water Pollution Prevention and Control for Taihu Lake Basin; this Plan was essentially the same as the 1997 Plan.
Heat waves: Shanghai and the rest of the YDR are experiencing growing numbers of increasingly severe heat waves. The annual number of extreme high temperature (EHT) days has increased steadily since the early 1980s (Fig. 14). More importantly, the number of days with severe temperature extremes has increased dramatically in the first half of this decade (Fig. 15).

*Figure 14: Extreme Temperature Days in Shanghai (1873 – 2005)*
*Source: reproduced from Shi (2006)*

*Figure 15: Changes in Severity of Extreme Temperature Days in Shanghai (1873 – 2005)*
*Source: reproduced from Shi (2006)*
3. Changes in Means

While changes in extremes have immediate, often catastrophic impacts, more gradual changes in means are more insidious, and therefore less likely to be perceived as a priority by policy makers. However, in many respects changes in means are likely to have a greater long-term impact on the livability of the YDR, on the health of its residents, and on the competitiveness of its metropolitan economies.

**Rising Surface Air Temperatures:** The mean annual temperature in Shanghai has increased by almost 2°C since the mid-1940s (Fig. 16). Projections suggest that the YDR will experience an additional increase of at least 2°C by 2050. Aside from health effects, including from increased ground-level ozone, warming is having a major impact on electricity consumption in the Region. Residential consumption has increased: from 380 kwh/person in Shanghai in 2002 to 535 kwh/person in 2006 (a 40% increase in four years); from 176 kwh/person in Jiangsu in 2002 to 255 kwh/person in 2006 (38.6% increase); and from 269 kwh/person in Zhejiang to 338 kwh/person (25.6%) (Lawrence Berkeley National Laboratory, 2008). Most of that increase in consumption is attributable to residential air conditioning.

![Figure 16: Mean Air Temperature in Shanghai, 1873–2005](image)

Recent research has found that the Yangtze Delta megalopolis as a whole has become a regional heat island (Chen, 2006). In Shanghai itself, heat island effects have become very pronounced. The map on Figure 17 shows population densities across the metropolitan region in 2000. These correlate highly with the very high surface-air temperatures recorded in June, 2006 (Fig. 18). The temperature difference between densely inhabited urban areas and outer rural areas was more than 10°C. Looking forward, we have estimated densities for 2030, based on the population estimate described earlier of 27 million residents (Fig. 19). The implication of rising temperatures, population growth, and continuation of spatial development trends is that Shanghai is likely to become one huge heat island across most of its territory.

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16 Population was distributed in a 1 km x 1 km based on land uses outlined in the Shanghai Master Plan, delineation of restricted development areas, and analysis of actual, largely uncontrolled development trends across the metropolitan region from 1990 to 2002 using high resolution satellite imagery (Chreod, 2008).
Figure 17: Population Densities in Shanghai, 2000 (16.4 million pop.)
Source: Chreod

Figure 18: Surface Air Temperature, June 21, 2006
Source: reproduced from Shi (2006)
If trends continue, by 2030 Shanghai will be comprised of a very dense core area, eight suburban satellite cities at relatively high densities, and large expanses of medium and low density sprawl spreading concentrically and in several corridors from the metropolitan core. This spatial pattern needs to be carefully assessed against the full range of probable climate changes to determine the metropolitan region’s vulnerability to their effects. Alternative forms of metropolitan growth (e.g. concentrated development in 2 to 3 corridors) might decrease vulnerability and decrease the costs of adaptation.

**Rising Sea Level:** Research in the late 1990s had already concluded that expected SLR impacts place Shanghai, the eastern lowland of the Taihu Basin, and the northern bank of Hangzhou Bay at ‘extreme risk’ of: 1) coastal recession, vertical erosion of tidal flats, and increasing length of eroding coastline; 2) increase in frequency and intensity of storm surges; 3) reduction of drainage capacity resulting from backwater effects in the Lixiahe and eastern lowland of Taihu Basin; and 4) increase in salt water intrusion up the Yangtze (Shi, 1999).

Relative SLR in Shanghai is heavily influenced by ground subsidence. The average rate of subsidence was 29 mm/year in the central part of the metropolis from 1921 to 1998 (Fan, 2006). Ground level in central Shanghai is currently less than 4.5 m with parts of the center (Jingan District) at 2.3 m. The highest tidal level recorded to date was 5.22 m in September 1991 (ESCAP, 2003). The mean land subsidence is projected to be 15 cm by 2030, and 17.3 cm by 2050, adding to the 1.76 m drop from 1921 to 1995. Most of Shanghai’s subsidence has been caused by excessive groundwater extraction.
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The State Key Laboratory of Marine Geology at Shanghai’s Tonji University now estimates that, accounting for subsidence, relative SLR in the Yangtze River Delta will range from 50 to 70 cm by 2050 (Fan, 2006). At a relative SLR of 30 cm, six times the area currently protected from tidal flooding in Shanghai and southern Jiangsu Province will be unprotected and exposed to flood risk (Fan, 2006). IPCC (2007) projects ground subsidence in the YDR of 2 to 2.6 meters by 2050, with a SLR of 50 to 70 cm by 2050, and a resulting area at risk of tidal and fluvial flooding of 54,500 km².

Recent estimates by Chinese hydrologists suggest that existing floodwalls in Shanghai, initially designed for a 1,000-year occurrence, will be able to withstand a 400- to 500-year occurrence in 2010, a 200- to 400-year occurrence by 2030, and a 100-year occurrence by 2050 (ESCAP, 2003). Much of the existing floodwall system is expected to have degraded beyond repair by 2030 and will need to be completely replaced.

Most of Shanghai will likely be vulnerable to SLR. While vulnerability of the central area is likely to be reduced by the contemplated construction of a flood gate near the mouth of the Huangpu River, dispersed patterns of development will expose large areas of the suburbs to both tidal and fluvial flooding. The current Master Plan for Shanghai calls for the continued development of four of the city’s six ‘pillar’ industries in coastal locations that are particularly vulnerable to storm surges (Fig. 20). While these pillar industries could be protected with new floodwalls, the balance of Shanghai’s manufacturing occurs in over 105 industrial parks dispersed across the metropolitan region along waterways that are likely to be subjected to fluvial flooding and waterlogging under SLR (Fig. 21).

![Figure 20: Location of ‘Pillar’ Industrial Bases by 2020](source: Shanghai Comprehensive Urban Development Master Plan to 2020)
Fluvial deceleration caused by SLR could have serious impacts on environmental health in Shanghai. The intricate network of rivers and canals that crisscross the metropolitan region extend for 25,000 km and occupy an area of 643 km², 10% of Shanghai’s total area (Tang, 2008) (Fig. 22). Flows are extremely difficult to model given the number and small capacities of much of that network, volatility of runoffs, and tidal patterns. What is clear, however, is that this network acts as a huge conveyor of Shanghai’s urban and agricultural runoffs, and multiple point discharges of both treated and untreated wastewater scattered across suburban parts of the metropolis. Shanghai’s location at the downstream portion of the Taihu Basin means that 70% of Taihu Lake drains through the Huangpu River which flows through the center of Shanghai before emptying into the Yangtze. In its comprehensive water quality survey in 2001 of 320 locations in the Taihu Basin, the Taihu Basin Authority found that 92.6% of water in the Huangpu River had a quality worse than Class V (which, according to national standards, means that it is unsuitable even for irrigation and industrial use); the remaining 7.4% was Class IV, i.e., unsuitable for drinking water. Water quality along the Huangpu has been steadily deteriorating for more than a decade.

A major concern with Shanghai’s municipal water treatment and distribution system is that it does not serve the rapidly expanding suburban areas. The blue areas shown on the map in Figure 22 delineate the small service areas of suburban District supply systems. The remaining areas of Shanghai obtain their drinking water from groundwater and directly from the network of polluted waterways.
Saline intrusion resulting from SLR is a major concern in coastal portions of the YDR, and especially for Shanghai. For five months in 1978/79, Chongming Island (Shanghai’s remaining county in the mouth of the Yangtze River) was completely surrounded by salt water when the Yangtze’s discharge fell below 7,300–8,000 m³/s (Fan, 2006). Saltwater can, when the Yangtze’s flows drop below 7,000 m³/s, encroach up to 100 km inland during the dry season.

Shanghai’s metropolitan raw water supply is highly exposed to pollution risk and, in the future, to SLR. The principal raw-water intake that supplies treatment plants in the municipal water system is located at Daqiao along the Huangpu River. This intake was constructed in 1994/95 after water quality 30 km downstream at the older intake at Linjiang was found to be too polluted.¹⁷ A 5-km buffer zone was established along the upper reaches of the Huangpu within which industrial and urban development was to be tightly controlled. However, the intricate network of waterways crossing from beyond that buffer continued to drain pollutants into the Huangpu River, enforcement of development controls within the buffer zone was inconsistent, and pollution from upstream in Jiangsu (Taihu Lake) and Zhejiang provinces continued unabated. Water quality has steadily worsened since completion of the Daqiao intake, and the Shanghai Municipal Government decided in 2003 to construct an entirely new intake in the middle of the Yangtze River to supply 70% of Shanghai’s needs.

¹⁷ The World Bank supported construction of the Daqiao intake through the Shanghai Environment Project (LN.3711).
The new raw-water supply project, costing $2.25 billion, is anchored on a new reservoir under construction at Qingcaosha on the northern tip of Changxing Island (Fig. 22). When completed by 2010, the reservoir will cover an area of 70 km² at a depth of 7 m, and will be connected by a raw-water conveyor tunnel to the mainland where it will be pumped and conveyed to key plants across the municipal service area. The reservoir will have a capacity of 500 million m³ and supply 7 million m³/d of raw water, which roughly accounts for 70% of Shanghai’s water supply. The reservoir has been designed to store the equivalent of 68 days of Shanghai's water supply needs in 2010. It will accept freshwater flows from the Yangtze and gates will be closed at high tide when saline intrusion is more likely to occur.

We understand that comprehensive hydrological modeling of saline intrusion risks based on relative SLR and upstream deceleration scenarios was not conducted for the new reservoir, for two reasons. The first was the urgency to provide another metropolitan raw-water intake, given the unexpected and continual degradation of water quality at the Daqiao intake on the Huangpu River. The second was that, despite several attempts to identify alternative sites further upstream in Jiangsu Province, Shanghai could not come to an agreement with provincial and relevant municipal authorities on site acquisition and operation. While the reservoir at Qingcaosha will have the capacity to store 68 days of Shanghai’s water needs, the 1978/79 experience of five months of saline intrusion around Chongming Island raises significant concerns over the sustainability of Shanghai’s water supply, especially given expected SLR over the next few decades.

A final concern with effects of SLR is the possibility of saline intrusion into the groundwater and waterway network from which the bulk of the suburban area currently obtains drinking water.

**Reduction in upper Yangtze source waters:** Sedimentation over the last 2,000 years has created much of Shanghai’s current land area. This process has been decreasing since the 1980s due to dams and reservoirs built upstream, including the Three Gorges Dam which was completed in 2003 (Saito, 2007). Decline in the rate of sedimentation, combined with SLR, is expected to accelerate erosion along sections of the YDR’s coastline; several key wetlands will be at increasing risk, affecting coastal water quality. The potential decrease in tidal flats could have significant impacts on coastal fisheries.

The YDR could be at risk from climate-related events occurring thousands of kilometers upstream. Melting Himalayan glaciers are an important source of the Yangtze River’s headwaters. As glaciers contract, the shrinkage of source waters could, despite regulation of flows at the Three Gorges, affect the amount and velocity of river flow at the Delta, which will be further reduced through abstraction of Yangtze water to supply the huge South-North Water Transfer Project, now approaching completion.

**Increased mean precipitation:** Although the annual number of rainstorm days in Shanghai has declined in the first half of this decade (Fig. 23), this appears to be a short-term episode,
especially given growing heat island effects that induce local precipitation. More relevant is the dramatic increase in volume of rain that has been falling during rainstorm days (Fig. 24).

![Figure 23: Annual Rainstorm Days, 1961–2005](source: reproduced from Shi (2006))

![Figure 24: Volume of Precipitation in Rainstorm Days, 1961–2005](source: reproduced from Shi (2006))

Much of the existing urban drainage system in Shanghai is antiquated, and designed with low runoff coefficients. Except for new areas in suburban districts, drainage systems in the old county towns remain rudimentary. Localized flooding and waterlogging are common across the
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metropolitan region during periods of heavy and sustained rainfall, and could well become serious local problems given the recent increase in rainstorm volumes.

This overview of some of the potentially critical effects and impacts of climate change on the YDR and Shanghai is admittedly cursory and incomplete. It underlines, however, the urgent need for the systematic preparation of comprehensive climate change adaptation strategies at two spatial scales: 1) for the Yangtze Delta as a whole, focusing on the megalopolis stretching from Nanjing through Shanghai to Ningbo; and 2) for each metropolitan region, especially Shanghai.

The key first step in preparing these strategies is to conduct rigorous vulnerability assessments that define exposure to the various climate changes, the probability of climate-related events occurring, and the capacities of cities and towns to mitigate negative impacts. Rigorous vulnerability assessments and the preparation and implementation of effective adaptation strategies depend on the pooling of information, knowledge and judgments from among multiple parties, and hence cooperation and coordination of a wide range of stakeholders, particularly governments.

IV. INSTITUTIONAL CHALLENGES TO EFFECTIVE ADAPTATION PLANNING

1. Current Constraints

There are two provinces, one provincial-level municipality, 15 Prefecture-level Cities, 17 County-level Cities, and 14 Counties in the Yangtze Delta Region. In Shanghai, the municipal government provides services principally to 13 urban districts within the Outer Ring Road; the 7 suburban districts and one remaining county are, under decentralization, required to provide most services through their own local governments’ fiscal resources.

China is a unitary state: relationships between levels of government are rigidly hierarchical, and functional responsibilities are delegated – not devolved – to lower levels of government. This means that hierarchical channels must be followed for all consultations between adjoining jurisdictions. For example, if Jiading District in suburban Shanghai wants to coordinate a plan or program with Kunshan City across the border in Jiangsu Province, its District government must take the request to the Shanghai Municipal Government, which in turn takes it to the Jiangsu Provincial Government, which then takes it to the Suzhou Prefecture-level municipal government, which in turn conveys the request to the government of the Kunshan County-level City. Kunshan’s response follows the same tortuous process up and down the hierarchy to Jiading District. Similarly, if Pinghu County-level City in Zhejiang Province has a request or initiative to propose with Jinshan District across the border in Shanghai, it takes it to the municipal government of Jiaxing Prefecture-level City, which takes it to the Zhejiang Provincial Government, which takes it to the Shanghai Municipal Government, which transmits the request or proposal to Jinshan District. Each of these steps requires explicit review by and written approval of the respective government and its affected commissions and agencies. The preparation and implementation of effective adaptation strategies will be severely constrained by

20 see Kamal-Chaoui et al (2009) for a description of China’s system of governance and municipal administration, and for a review of various forms of ‘decentralization’ that have occurred in China since the late 1980s.
this structure of governance since climate events pay no heed to administrative boundaries and jurisdictions. Efficient cross-boundary cooperation and inter-jurisdictional coordination are essential for effective and consistent adaptation.

2. Adapting to Changes in Extremes

In examining the potential impacts of changes in extremes as described in this paper, three key institutional implications for adaptation measures become apparent (Fig. 25). The majority of adaptation measures will need to be taken at the metropolitan region scale which will require very close coordination between municipal governments (that currently focus their efforts on urban districts) and suburban district governments. The historical tendency of municipal governments to ignore suburban districts (formerly, rural counties) needs to be reversed: urbanization in the Delta has ruptured past these old city boundaries. Functional responsibilities, organizational structures, and planning and programming processes need to be realigned within municipalities so that strategic measures, such as those required for climate change adaptation, can be effectively designed, financed, and implemented.

![Figure 25: Institutional Implications of Changes in Extremes](image_url)
Cross-boundary coordination between municipalities and sub-municipalities will be of particular importance in planning for disruption to strategic infrastructure from cyclones and storm surges, especially expressways, railways, and power infrastructure.

Inter-municipal coordination will be critical for managing disruptions to strategic infrastructure, balancing power supply during heatwaves, and in managing spikes in surface water pollution during cyclones and droughts.

3. Adapting Changes in Means

Similarly, the majority of adaptation measures to changes in means will need to focus on the metropolitan region scale, making improvements to municipal/district coordination a top priority (Fig. 26). Cross-boundary coordination, already an urgent requirement in the Delta, will become essential for dealing with impacts on water quality from SLR, increased mean precipitation, and fluvial deceleration. Inter-municipal coordination across most of the YDR will be important for dealing with surface-water pollution, coastal pollution, and species reduction.

**Figure 26: Institutional Implications of Changes in Means**
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4. Adaptation at the Yangtze Delta Region Scale

At the YDR level, a regional adaptation strategy will require unprecedented coordination between the provinces, Shanghai, and municipalities. Given its unitary structure, the central government will need to take the lead and principal responsibility for a YDR-wide adaptation strategy.

There is a recent and relevant precedent for such a wide-ranging central coordinating role. Despite efforts for coordinating Five Year Plans between the Delta’s provinces, competition and insularity have continued. Recognizing the YDR’s growing national economic importance, State Council directed the National Development Reform Commission (NDRC) to prepare a long-term development strategy for the Delta that covers all 15 Prefecture-level Cities and Shanghai. NDRC’s team was able to exercise its authority over the provinces and cities and prepare the long term strategy; it is reportedly ready for submission to State Council for review and approval by the end of May 2009 after which it will be announced publicly. Indications are that it will be a uniquely important and comprehensive strategy to which sub-national governments will need to fully conform. Given this recent experience, NDRC should likely take the central government lead in preparation of a YDR adaptation strategy.

Top-down direction – rather than coordination by the center – is not likely to garner support or commitment of sub-national governments in the YDR. Discord among the two provinces and Shanghai, and intense competition between municipalities in the YDR throughout the 1990s, led the central government to mandate the formation of four institutional mechanisms to foster intra-regional cooperation within the YDR at the start of this decade.

An annual Summit Meeting of YDR Governors (Jiangsu and Zhejiang Governors, Mayor of Shanghai) has been held since 2001, at which regional issues and actions are reviewed and priorities for cooperation are set for the year. Flowing from these Summit Meetings, an Economic Cooperation and Development Conference is held annually in Jiangsu, Shanghai, and Zhejiang in turns, and attended by Executive Vice Governors of Jiangsu and Zhejiang and the Executive Vice Mayor of Shanghai. The major purpose of the conference is to promote the implementation of initiatives of regional cooperation identified by the Summit Meeting of YRD Governors. A permanent liaison secretary and thematic groups have been established to support the conference each year. A Joint Meeting of YRD Cities on Economic Cooperation of Mayors from the 16 YRD cities meets annually to discuss the implementation frameworks for the regional cooperation program addressed by the Economic Cooperation and Development Conference of Shanghai, Jiangsu and Zhejiang. The meeting focuses on the discussion and resolution of the practical issues of regional cooperation in YRD. At the Joint Meeting thematic groups address: regional planning, transportation, energy, communication, tourism, eco-environment, human resource, and innovation. Parallel to the Joint Meeting of Mayors, Sectoral Joint Meetings on regional human resources issues, regional environment and pollution control,

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21 This is the second time that the central government has gone below the provincial level to develop strategies covering sub-provincial regions. The first was the preparation of the new Pearl River Delta Long Term Development Strategy which was approved by State Council in December 2008. Until now, the central government dealt almost exclusively with provincial governments.

22 Especially the inability of governments to effectively stem pollution in the Taihu Basin; a decade of disagreement during the 1990s between Shanghai and Zhejiang Province on location of the new deepwater port (which finally forced State Council to mediate); and the inability of Shanghai and Jiangsu to agree on terms for a less risky location for Shanghai’s new metropolitan raw water intake.
regional transportation integration and other themes are held with Directors-General of provincial and municipal governments. To our knowledge, adaptation to climate change has not yet been addressed by any of these four mechanisms.

5. Moving Forward

Admittedly, these institutional instruments are relatively new and, so far, largely consultative. However, they do provide, for the first time, an institutional framework through which joint planning of adaptation strategies could evolve, especially if coordinated by NDRC on behalf of the central government. Given the YDR’s high and growing exposure to climate-related risks, NDRC should take the opportunity presented by imminent State Council approval of its YDR Development Strategy to quickly mobilize these nascent intra-regional coordination mechanisms in the preparation of a YDR climate change adaptation strategy that could become a best practice model globally.23

A key first step needs to be the application of the best scientific knowledge in the world to clearly and accurately assess the various risks of climate change on the Delta, and the vulnerability of municipalities to these risks. This best global knowledge is, so far, conspicuously absent in Shanghai and the YDR. Given its strategic national economic importance, the task of mobilizing and applying such knowledge should be spearheaded, in our view, by the Office of the Premier.

Such an initiative could well benefit from World Bank knowledge and support given its extensive experience since the late 1980s in urban environment projects in Shanghai, Jiangsu, and Zhejiang, and the Bank’s growing climate change experience with cities around the world.

23 The London climate change adaptation strategy, published for discussion in August 2008, could provide a model for such a strategy for the YDR and for its constituent metropolitan regions, especially Shanghai (Greater London Authority, 2008).
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