Climate's Long-term Impact on New Zealand Infrastructure (CLINZI) - A Case Study of Hamilton City, New Zealand

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Abstract

Infrastructure systems and services (ISS) are vulnerable to changes in climate. This paper reports on a study of the impact of gradual climate changes on ISS in Hamilton City, New Zealand. This study is unique in that it is the first of its kind to be applied to New Zealand ISS. This study also considers a broader range of ISS than most other climate change studies recently conducted.

Using historical climate data and four climate change scenarios, we modelled the impact of climate change on water supply and quality, transport, energy demand, public health and air quality. Our analysis reveals that many of Hamilton City's infrastructure sectors demonstrated greater responsiveness to population changes than changes in gradual climate change. Any future planning decisions should be sensitive to climate change, but not driven by it (even though that may be fashionable to do so).

We find there is considerable scope for extending this analysis. First, there is a need for local infrastructure managers to improve the coverage of the data needed for this kind of study. Second, any future study of this kind must focus on daily (rather than monthly) time steps and extreme (as well as gradual) climate changes.

Key words

Climate change, infrastructure, integrated assessment, adaptation

Acknowledgement

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[1] This project would not have been possible without assistance from several local Hamilton agencies. In particular, the Hamilton City Council has provided significant assistance with data collection across a range of different areas. The project has also benefited from the strong support of WEL Networks and Transit New Zealand.

1 Introduction

The Earth's climate is changing at unprecedented rates. As a result of higher greenhouse gas concentrations, global average surface temperature has increased by about 0.6˚C over the 20th century with the 1990s probably the warmest decade in instrumental record (IPCC 2001). This average global change masks regional variations. For example, higher latitudes in the northern hemisphere have warmed more than the equatorial regions (Office of Science and Technology 1997). Recent climate change in the Southern Hemisphere is marked by a strengthening of the circumpolar westerlies in both the stratosphere and the troposphere (Gillet and Thompson 2003)

Climate changes of these proportions will invariably effect human structures and activity. One impact of particular importance is the effect of climate change on infrastructure systems and services (ISS). The services provided by infrastructure are numerous, including flood control, water supply and energy distribution. Their real value lies in the contribution of such services to economic development and quality of life.

ISS are very sensitive to climate. While several international researchers have shown that the possible damages to ISS as a result of climate change are the same or larger than damages to agriculture (see Ruth *et al.* 2005), there have been surprisingly few integrated assessments of the impact of climate change on ISS in New Zealand (see for example (Cohen 1996, 1997, Huang et al. 1998, Bloomfield et al. 1999, Rosenzweig et al. 2000, Koteen et al. 2001, Schmandt and Clarkson 2005)).

The primary purpose of this paper is to explore and quantify potential impacts of gradual climate change on the ISS in Hamilton City, New Zealand.

2 Research background

ISS deserve special attention in the climate-change debate. To date, most of the work on the impacts of climate change has focussed on individual sectors of an economy, with particular attention given to the impacts of climate change on agriculture (Bloomfield *et al.* 1999). However, the number of studies conducted on regional impacts of climate change, including impacts on urban areas, is increasing (e.g., the National Institute of Water and Atmosphere's "Adaptation to Climate Variability and Change" programme[2]). Most of these studies are sector specific, concentrating, for example on implications of climate change for water supply or air quality. Few studies integrate impacts across sectors to capture possible ripple effects and interdependencies. Table 1 lists the main studies and compares the areas on which they focus and the extents to which they address interdependencies.

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[2] See http://www.niwa.cri.nz/rc/prog/c01x0202.

Table 1: CLINZI and its Predecessors

	(Koteen *et al.* 2001)	(Rosenzweig *et al.* 2000)	(Kirshen *et al.* 2004)	(Amato *et al.* 2005)	CLINZI
Location	New York City, USA	Greater Los Angeles, USA	Metropolitan New York, USA	Metropolitan Boston, USA	Hamilton, New Zealand
Sectoral Coverage					
Water Supply	X	X	X	X	X
Water Quality				X	X
Water Demand				X	X
Sea-level Rise	X		X	X	N/A
Transportation				X	X
Communication					
Energy			X	X	X
Air Quality		X			X
Public Health					
Vector-borne Diseases	X				
Food-borne Diseases					
Temperature-related Mortality	X	X		X	X
Temperature-related Morbidity					X
Air-quality Related Mortality			X		X
Air-quality related Morbidity	X	X	X		X
Other					
Ecosystems					
Wetlands	X		X		
Other (Wildfires)		X			
Extent of					
Quantitative Analysis	Low	Medium	Medium	High	High
Computer-based Modelling	None	Low	Low	High	High
Scenario Analysis	None	None	Medium	High	High
Involvement of					
Local Planning Agencies	None	None	High	High	Low
Local Government Agencies	None	None	High	High	Medium
Private Industry	None	None	None	Low	Low
Non-profits	None	None	Low	High	None
Citizen	None	None	None	Medium	None
Identification of					
Adaptation Options	X	X	X	X	X
Adaptation Cost			X	X	
Extent of Integration Across Sectors	None	None	Low	Medium	Low/ Medium

2.1 The need for regional/local focus for climate change studies

Studies of infrastructure sensitivities to climate and climate change should be performed at the local or regional scale for a number of reasons (Patterson *et al. in press*) First, global climate change is anticipated to have geographically distinct impacts. For example, global climate models predict the annual average rainfall will increase in the west of New Zealand but decrease in many eastern areas (Boustead and Yaros 1994). As a consequence, analyses that apply a uniform temperature increase over nations may miss important geographic impacts on infrastructure. The ability to capture and interpret geographical variations in climate change impacts on infrastructure systems is particularly important for New Zealand due to its diverse climate.

A second justification for carrying out a local or regional assessment lies in the differences of infrastructure systems within regions (Lakshmanan and Anderson 1980, Sailor and Munoz 1997). Regional infrastructure systems differ in terms of physical structures, age of assets, institutional structures.

A third justification is that different sectors exhibit distinct sensitivities to climate. Since sectoral compositions vary across regions, the structure of a region's economy significantly influences the sensitivity of that community to climate (Penney 2001).

For these reasons, the current study focuses on Hamilton City – a medium-sized urban centre in New Zealand.

2.2 The case study area– Hamilton, New Zealand

Hamilton City is situated in New Zealand's North Island (Figure 1) along the banks of the Waikato River. A major service centre for the Waikato region, which has a strong agricultural sector, Hamilton is also strategically located 126 km from Auckland, New Zealand's largest city.

The City is home to more than 115,000 people and occupies 9,400 hectares.

Figure 1: Location map showing Hamilton in the North Island of New Zealand

Statistics New Zealand project Hamilton City's population to increase over the next 25 years (Statistics New Zealand 2000). Assuming maximum population growth, Hamilton is expected to reach around 179,000 by 2030 (Table 2).

Table 2: Hamilton City population projections from Statistics New Zealand

	Low	Medium	High
Population	150,381	164,476	178,891

3 Climate change for Hamilton City

To explore potential future performance of infrastructure in Hamilton City, we first collected historical data on temperature, precipitation, humidity, wind speed, and gust speed from the Ruakura stations for the period 1940–2004 (Vogel and Shallcross 1996). Some of the data are available at hourly, daily and monthly reporting intervals. From these data, we created monthly time series, standardised to a month length of 365/12 days. From the historical data we sampled observations using moving block bootstrapping (Houghton *et al.* 2001) and created new time series to simulate possible future climate conditions for the years 2005–2030, such that the new time series exhibits the same intra-annual statistical properties as the historic data. Repeating the process 50 times then yields 50 alternative futures.

In a second step of our analysis we applied regional trends from climate scenarios developed by the National Institute of Water and Atmospheric Research (NIWA), which in turn are based on the CSIRO and Hadley models (Energy Efficiency and Conservation Authority 2004) for a total of four climate change projections (Table 3 and Table 4). With these trends, we have five sets of 50 scenarios: a base scenario assuming future climate to be, in essence, like the past, and four alternative scenarios consistent with historical patterns *and* possible future climate change trends as derived from global circulation models.

According to Mullan (*pers. comm.*), relative humidity remains fairly unchanged in most climate modelling scenarios. Also, wind gusts cannot be scaled specifically from monthly data (Mullan *pers. comm.*). Humidity and wind gusts were not included in our climate projections or in our analyses.

Table 3: Modelled Temperature Change (^{o}C) between 1990 and 2030s under four climate change scenarios at Ruakura station (Mullan *pers. comm.*)

Season	S1: CSIRO Low	S2: CSIRO High	S3: Hadley Low	S4: Hadley High
summer	0.38	0.82	0.23	0.49
autumn	0.47	1.03	0.24	0.52
winter	0.35	0.75	0.4	0.87
spring	0.29	0.62	0.3	0.65

Table 4: Modelled Precipitation Change (%) between 1990 and 2030s under four climate change scenarios at Ruakura station (Mullan *pers. comm.*)

	S1: CSIRO Low	S2: CSIRO High	S3: Hadley Low	S4: Hadley High
summer	-12.7	-5.8	-2	-0.9
autumn	0.7	1.5	-5.8	-2.7
winter	-1.8	-0.8	5.5	12
spring	-2.9	-1.4	-12	-5.5

The bootstrapped projections for temperature and precipitation showed a progressive increase in temperature (Figure 2) and an increased range of monthly precipitation (Figure 3) over the 2005–2030 period. The CSIRO High scenario results in the greatest monthly maximum temperature by 2030, and the Hadley Low scenario in the lowest monthly minimum temperature (Figure 2), which is still higher than that in the base-case scenario. Higher monthly precipitation is projected in the Hadley High scenario, while the lowest monthly precipitation projections occur on the CSIRO Low scenario (Figure 3).

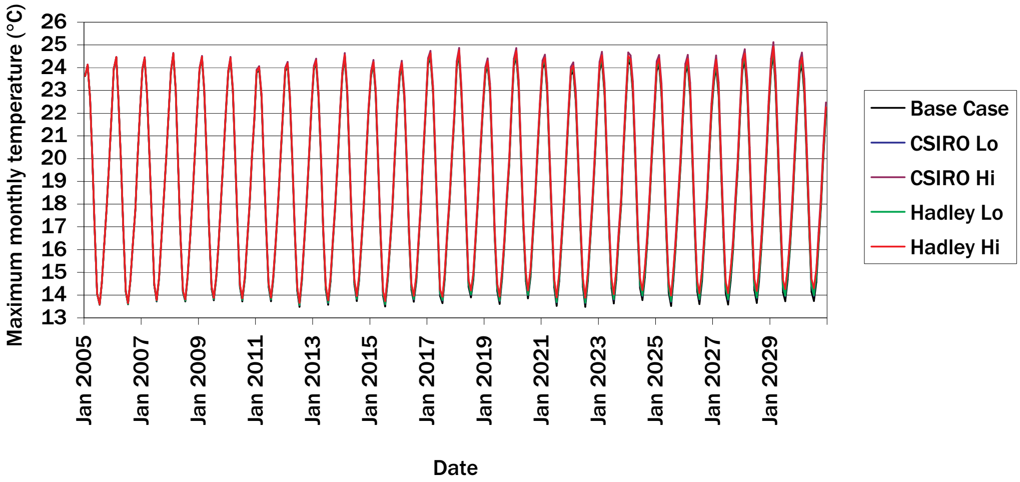

Figure 2: Projected temperature regimes for Hamilton, 2005–2030, based on historical temperature (base case) and four climate change scenarios

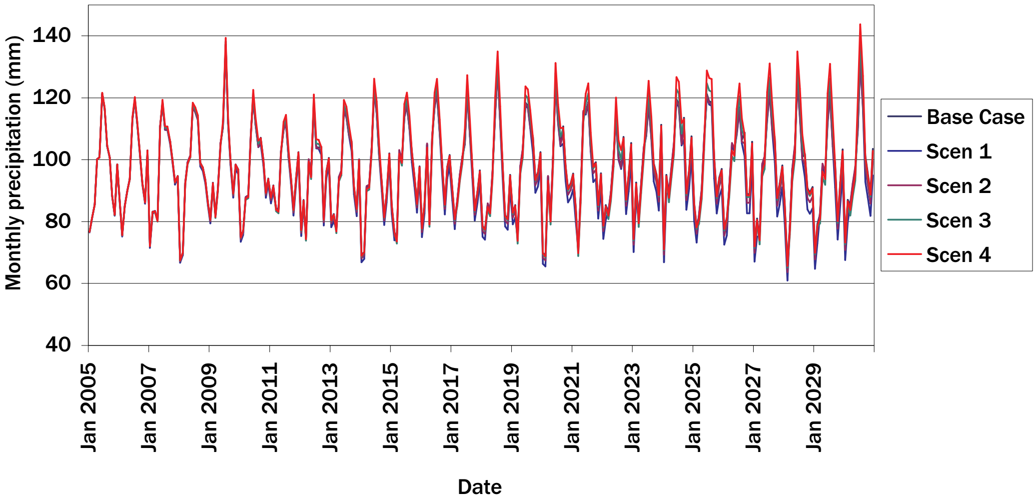

Figure 3: Projected precipitation regimes for Hamilton, 2005–2030, based on historical precipitation (base case) and four climate change scenarios

4 Methods overview

This study focuses on the interrelated performance of water supply, transport, energy, air quality, and public health under different assumptions about future climate. These sectors were chosen because they present vital components of the quality of life and economic activity in Hamilton City, and because at least a minimum amount of reliable and detailed data was available to establish empirical relationships between climate variables and system performance. Several other sectors, most notably communication and flood control, are not analysed here because of a current lack of access to data at the level and detail needed to carry out statistical analyses and computer modelling.

On the basis of historical information we estimated the functional relationships between climate variables (see Appendix A) and observed infrastructure (dependent) variables. For each of these regression equations, we conducted standard statistical significance tests and, where necessary, we corrected for autocorrelation (using either Yule-Walker or Prais-Winsten transformations) and heteroscedasticity. For many of the models we employed monthly dummy variables for January–November to control for non-climate-related intra-annual variation in the dependent variables.

The regression results were used to calculate potential future demand on the infrastructure system for assumed changes in economic activity and population size, as well as the five different sets of climate scenarios described above. For all models we ran sensitivity analyses for the functional specifications of each model in which we sampled parameters from a normal distribution around the mean parameter estimates in the regression results. Fifty such sensitivity runs were conducted for the base case and compared with the results (and standard deviations) derived from mean parameter estimates. The variation of results observed in those 50 sensitivity runs was within the range of results generated by the 250 model runs.

Due to data and resource limitations, none of the results capture the impacts of extreme events or reveal impacts experienced at hourly or daily, rather than the modelled monthly time scale. Our focus on Hamilton City further limited our ability to explore the obvious interactions between Hamilton city infrastructure and the outlying areas.

5 Results and Discussion

The following sections summarise the results for climate impacts on water supply and quality, transport, energy demand, public health and air quality. In addition, we discuss the integrated impacts across the range of ISS.

5.1 Water (supply and quality)

Hamilton operates a single water treatment facility with a capacity of 85 ML per day. Water is drawn from the Waikato River, filtered and treated for drinking and stored in one of eight water-storage facilities in the city (a total capacity of 90.2 ML) until it is piped to residential, commercial, and industrial end-users. If climate change produces conditions that lead to heightened water use, this supply capacity could require extension to keep pace with demand.

Furthermore, climate changes may make it either harder or easier to clean river water (increased rainfall might stir up more debris, while shifting temperatures could increase or decrease biological activity). Using turbidity as a proxy for how difficult the river water is to process, we also produced a model projecting climate change's impact on water processing.

Based on the regression analysis described in Appendix B, we found a significant and positive relationship between per capita water consumption and two temperature variables (MeanLgtTemp and Streaks26_3day (see Appendix A for a list of variables) and two measures of rainlessness (MaxRainlessStreak and DaysNoRain). The rainfall variable, Max3DayRain, exhibits a significant and negative relationship.

For water quality (turbidity) the regression analysis (Appendix B) indicates that every rainless day and every frost day lowers water turbidity. This is consistent with expectations because rain tends to wash debris into the river, which increases turbidity, and frost days retard biological activity, which can cloud waters.

Using the functional relationships between water supply and quality and the socioeconomic and climate scenarios reveals that water usage is likely to increase under every scenario as a result of population growth

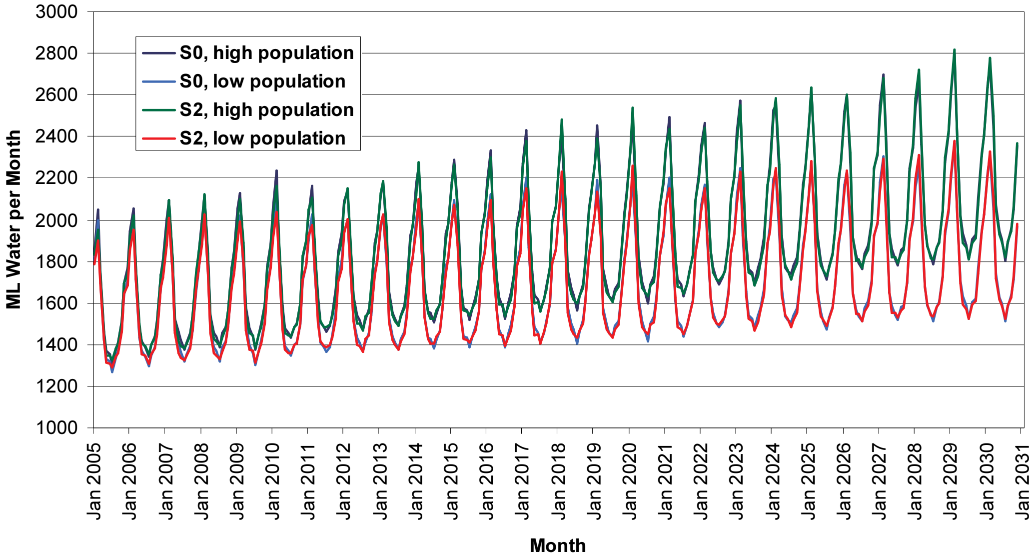

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Figure 4). By 2030, peak summer usage is 2800 million litres (ML) under a "high" population projection, compared with 2350 ML under a "low" population projection. The impact of different climate scenarios, however, is much smaller. As

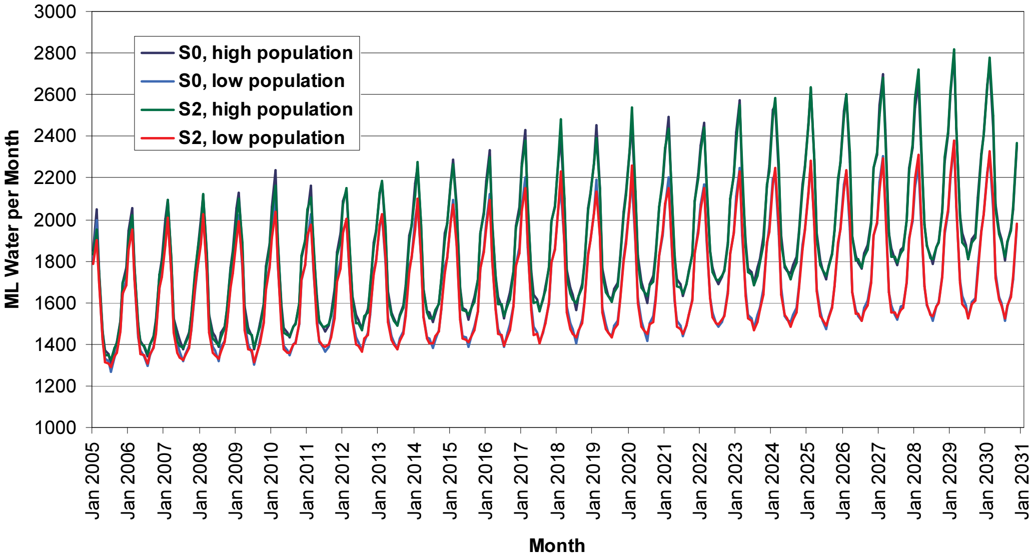


Figure 4 shows, the difference between the base-case scenario (S 0) and one of the more extreme climate scenarios (S 2) is negligible. Numerically, the difference amounts to less than 1%. Despite the significance of climate variables in water consumption, the small magnitude of the change during the next 25 years results in an equally small magnitude of climate-change induced changes in water consumption.

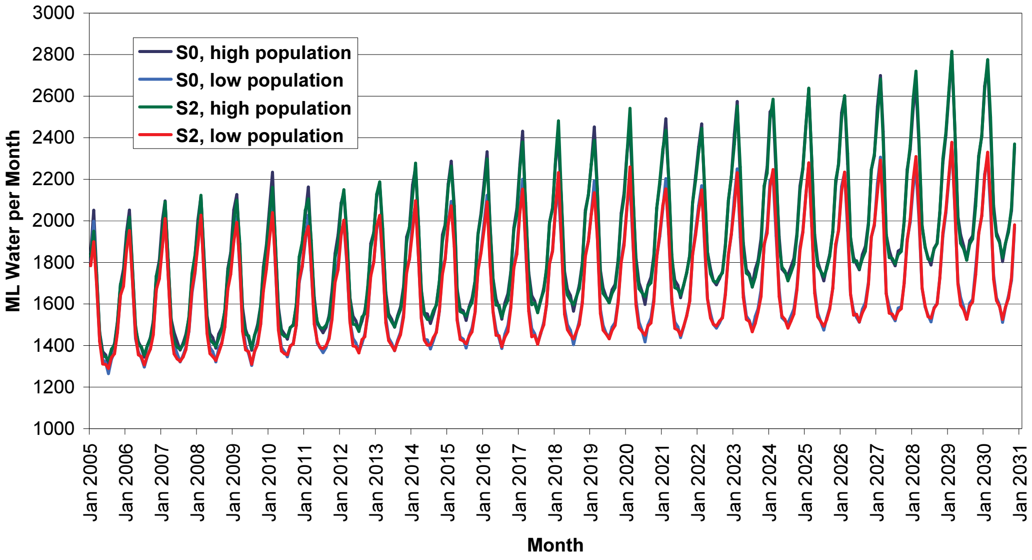
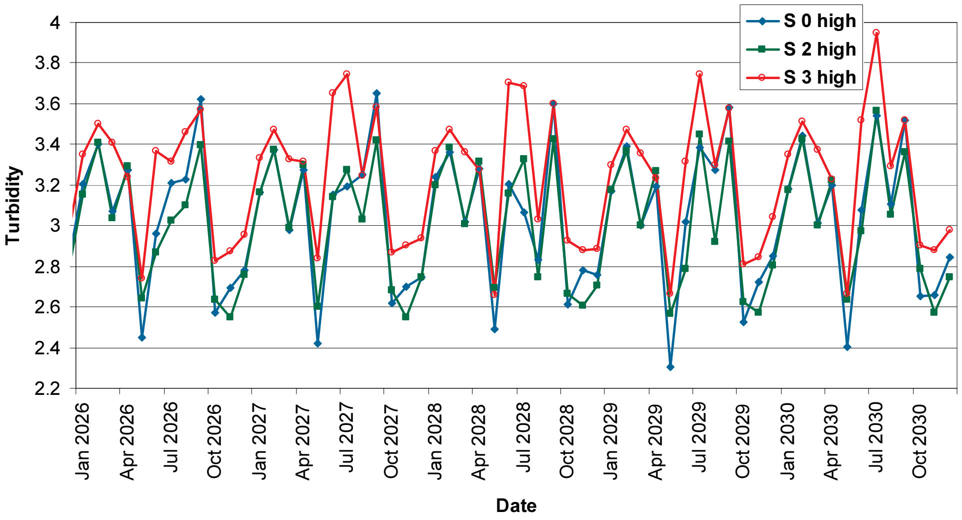


Figure 4: Hamilton City water usage, 2005–2030

Turbidity, as modelled, was not affected by the differences in population projection. However, the impact of differences in the climate scenarios was more noticeable than it was for water use.



As Figure 5 shows, by the end of the projection (2026–2030), monthly turbidity averages are different – on the order of 10–20% – between two climate scenarios and the base case.[3] Scenario 2, the CSIRO high projection, has the largest increases in temperatures of the four scenarios while exhibiting relatively small changes in precipitation. During winter months, as frost days are pushed lower, turbidity tends to be higher in the scenario than the base case, although scenario outcomes are still relatively close to the base case (S0). For Scenario 3 (S3), the Hadley low projection, temperature changes are roughly half those of Scenario 2 (S2), but the changes in precipitation are much more significant. The result of S3, according to the model simulations, is a general increase in the turbidity of water for treatment in Hamilton City.

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[3] To show the results in greater detail, the time series is truncated to the last five years of the projections.

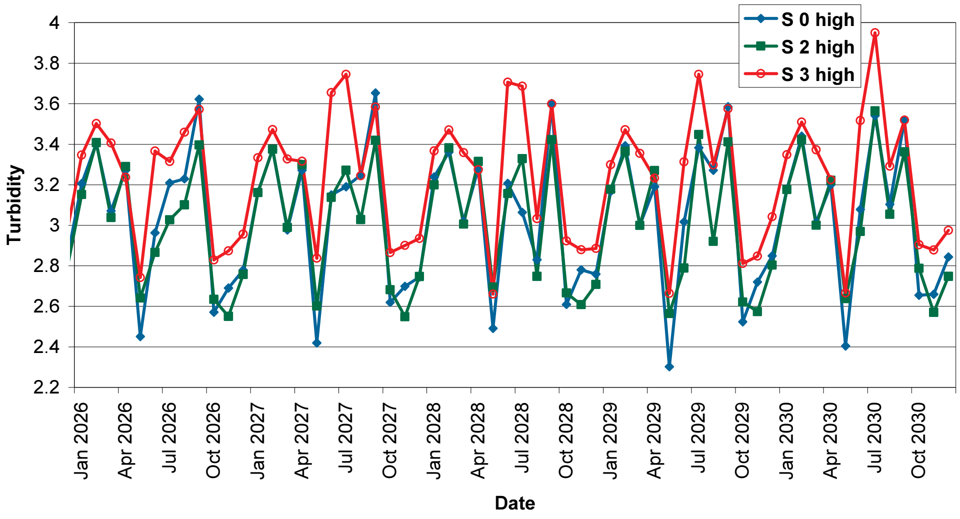

Figure 5: Turbidity projections, 2005–2030

This analysis offers a number of key insights into the next 25 years of drinking water supply/demand in Hamilton and possible policy orientations that can address these. First, changes in water demand (at the monthly aggregate level) are largely driven by changes in population, and not significantly affected by changes in climate. Policy makers would be wise to continue to focus on demographics when planning water system upgrades. These decisions should be sensitive to climate change, but not driven by it (even though it may be fashionable to do so).

Second, as temperatures warm and rainfall increases, Hamilton should expect the turbidity of its waters increase. While decreases in water clarity should have negligible impact on water treatment costs, city planners should keep such changes in mind when making equipment investment decisions. This thinking also extends beyond turbidity and water treatment, in that some of the more subtle impacts of climate change – such as water clarity – may be where the City will face unforeseen impacts on infrastructure capabilities. Hamilton City would be wise to consider other factors, beyond turbidity, that may influence the costs and/or effectiveness of water treatment and ascertain whether changes in climate could lead to changes in these factors which in turn lead to costly changes in equipment or processes needs.

Overall, Hamilton City's water system appears well suited for facing the changes in climate predicted over the next 25 years.

5.2 Transport

Hamilton City's transport system is dominated by road[4] vehicle transport. Road length (in kilometres) in Hamilton City has grown on average by 1.7% per annum since 1991 and vehicle-kilometres travelled increased from 465 million in 1999 to 545 million in 2004.

Our analysis of climate impacts on road transport is based on data for cost of road repairs of Hamilton City (cf state-owned) roads collected by the Hamilton City

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[4] A significant rail corridor passes through Hamilton City, but this is mostly used for through freight from Tauranga to Auckland. The Waikato River is also used for transport, but this is negligible.

Council's transportation unit. No data for costs of repairs on state roads in the area could be obtained from Transit New Zealand. Data for the number of vehicle trips in Hamilton City come from seven permanent traffic monitoring stations maintained by the city council's transportation unit.

The estimated relationship between climate and road repairs (see Appendix C) does not include temperature-related independent variables. This was consistent with comments made by the Roads and Traffic Unit's Asset Systems Manager that the major cause of road damage in Hamilton is prolonged periods of rain (Cantlon, *pers. comm.*). Consistent with Cantlon's observations, the amount of rain above 20mm per day was significant (at the 10% level) and positive – the more days with more than 20mm of rain, the more repairs were necessary. Similarly, the rainless streak variable has a significant and negative coefficient – longer periods with no rain reduce the costs of road damage in a given month.

The statistical model for trips per capita (see Appendix C) demonstrates that extended hot weather and heavy rainfall both correspond to depressed driving activity in Hamilton City. However, variability in driving behavior is rather low to begin with, reflecting relatively little net climate impact on driving decisions on these roads.

In every scenario, total trips are projected to increase due to population growth. By 2030, total trips peaks over 5.4 million under a "high" population projection, compared with 4.5 million under a "low" population projection. The impact of different climate scenarios, however, is much smaller. The difference between the base case scenario (S0) and one of the more extreme climate scenarios (S3) amounts to less than 0.2%. Despite the significance of climate variables in explaining the variation in monthly trips taken, the small magnitude of the change during the next 25 years combined with low variability in monthly trips results in a small magnitude of climate-change induced changes in the number of trips. Thus, in planning for changes in transport volumes and patterns, city planners should continue to pay more attention to issues of economic and population growth than to gradual climate change.

Scenarios showed that road repair costs are tied to population growth. There are significant differences between repair cost projections under high and low population growth forecasts. On average, the high population scenarios have roughly 20% more road repair costs than the low growth cases.

Projected changes in rainfall lead to higher repair costs during the spring for Scenario 2 (37% higher) and during the winter for Scenario 3 (34% higher) (Figure 6). Decreases in rainfall during the spring and autumn for Scenario 3 balanced some of these costs increases by decreasing costs during those months relative to the base case. By 2030 we project 6% and 9% increases in road repair costs under Scenarios 1 and 2 respectively, while Scenarios 3 and 4 yield no change in the annual costs of repairs and a 4% reduction respectively (Table 5). While the changes translate into only small monetary monthly costs, they do highlight the need to pay attention to the impact of climate change at finer levels of detail. Clearly, for road repair costs, the assumptions we make about how Hamilton's climate will change impacts on the magnitude and direction of the projected changes.

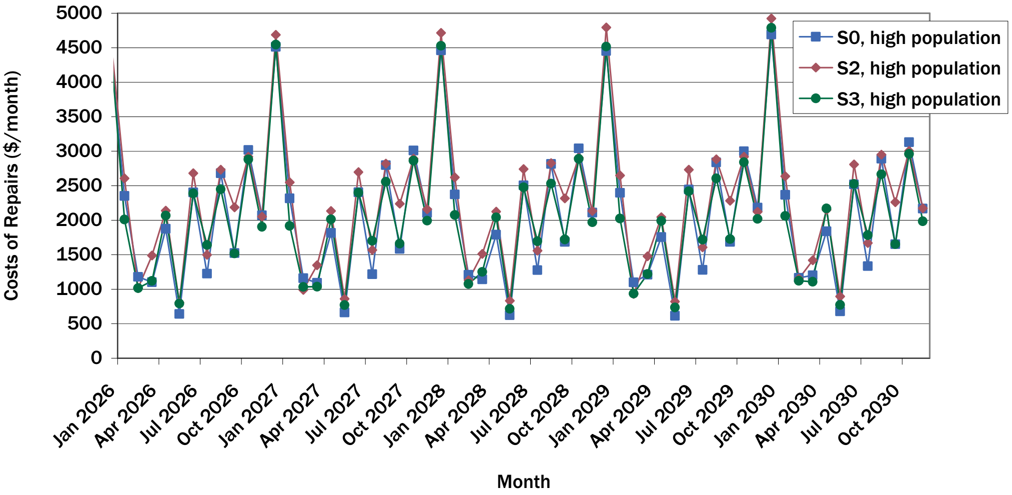

Figure 6: Projected costs of repairs under different climate scenarios, 2026–2030

Table 5: Annual costs of road repairs relative to base case as of 2030

Scenario	Change in cost
S1	+6%
S2	+9%
S3	+0%
S4	-4%

5.3 Energy

The CLINZI energy module concentrates on impacts of climate change on electricity use and distribution assets. This was dictated by three considerations. First, electricity is one of the largest sources of energy in Hamilton City (Energy Efficiency and Conservation Authority 2004). Second, electricity use data at the desired level of temporal (monthly) and spatial (Hamilton City) detail are readily available. Unfortunately, this is not the case for other sources of energy such as natural gas, petroleum and wood. Third, as with most areas in New Zealand, Hamilton City has a relatively high temperature-sensitive electricity load (about 17% of total Hamilton City electricity load (1996)).

For our analysis, Hamilton City electricity use data were obtained from New Zealand's Electricity Commission. Half hourly electricity distribution data (in kW) through the Hamilton area substation were available for the period 1 April 1984 to 31 March 2005. These data were aggregated to provide per capita monthly daily average electricity data.

With respect to physical distribution infrastructure, Hamilton City is fed by three substations, each operating 3-phase transformers, totalling 118 MVA theoretical capacity. However, the network is always operated to allow for one 23 MVA transformer to fail at any one time (Blackburn pers. comm.). This means available capacity is essentially 95 MVA (or an equivalent of 81,225 kW)[5].

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[5] Assuming a power factor of 0.95 and an availability of 0.9 (R. Blackburn, pers. comm.).

Regression analysis (see Appendix D) suggests Hamilton City's average daily electricity consumption per capita is sensitive to changes in the total heating degree days (HDD) during the month, calculated for 24-hour mean temperatures using 15°C as the threshold (HDD24_15). Electricity consumption in Hamilton is also influenced by the number of working days in the month (as a proxy for the economic activity in that month), a yearly dummy variable to account for changes in demand patterns that occur over time, monthly dummy variables to account for seasonal changes, and heating degree days in May and July. The two monthly HDD variables were dominant in the model, indicating people are more sensitive to changes in temperature in May and July as they 'acclimatise'.

This model is similar in many ways to the model estimated by Fitzharris and Garr (Fitzharris and Garr 1996) for New Zealand as a whole. Our model is also similar to the model developed by Amato et al. (Amato et al. 2005) who find that when controlling for socioeconomic factors, degree day variables have significant explanatory power in describing historic changes in electricity demand.

In our modelling framework, climate appears to have limited impact on electricity demand. Despite the significance of climate variables in explaining the variation in monthly electricity consumption, the small magnitude of the climate change during the next 25 years results in limited climate-change induced changes in electricity consumption. In Figure 7 there appears to be little difference between climate scenarios. The two 'low climate-change' scenarios, not surprisingly, exhibit the least difference in electricity consumption to the base case (Table 6). Of these two scenarios, scenario 3 (Hadley Low) suggests the least impact. The mean difference of this scenario from the base case across the whole period is only 0.08%. As expected, the variation from the base-case increases over time. The minimum difference in electricity consumption of scenario 3 from the base case occurred in April 2005, while the maximum reduction in electricity demand of 0.41% occurred in March 2026.

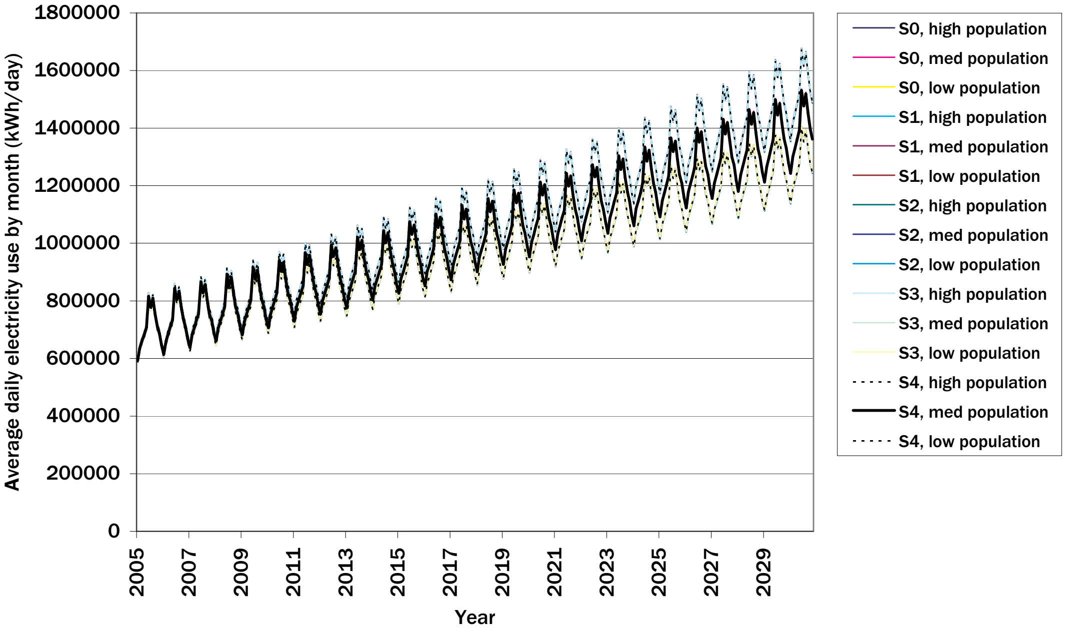

Figure 7: Electricity use for all 15 Scenarios, 2005–2030

Table 6: Summary statistics from the four scenarios, Percent difference from the Base Case

Scenario	Mean	Std Dev	Maximum	Minimum	Range
1	-0.12%	0.07%	-0.52%	-0.003%	0.52%
2	-0.25%	0.13%	-0.77%	-0.015%	0.76%
3	-0.09%	0.05%	-0.42%	-0.005%	0.41%
4	-0.17%	0.09%	-0.54%	-0.013%	0.53%

Analysis of base-case forecasted average daily Hamilton City electricity use (kWh/day) and scenarios over the calendar year reveals that, on average, base-case electricity use is forecast to follow the same pattern as historical consumption. That is, electricity use increases from an average summer minimum of 952,000 kWh/day in January to an average June maximum of 1,223,000 kWh/day. Note that average electricity consumption in July tends to be lower than other winter months of June and August. Monthly electricity use declines after August.

As noted above, Hamilton City's capacity infrastructure is relatively robust. However, two areas of potential interest are climate's impact on the proximity of peak-load electricity consumption to supply capacity constraints (see above) and climate's impact on conductor resistivity. Our analysis suggests Hamilton City is well endowed with supply capacity. Hamilton's electricity consumption, and its progress towards the supply constraint, are more affected by the city's population than by climate, and even in the high population scenario, power consumption in 2030 falls well below the supply constraint.

The impact of climate changes on conductor performance is also interesting to investigate because the performance of the electricity supply circuit significantly affects the quantity of electricity that can be supplied to consumers. In general, the higher the ambient temperature, ceteris paribus, the higher the resistivity of the circuit, until a design maximum, at which stage system failure is likely. Hamilton City supply cables are all underground and are designed for the following climate parameters[6]:

- ground temperature (summer mean daily maximum) 25°C
- air temperature (summer mean daily maximum) 28°C.

As none of the climate scenarios predict increased summer mean daily maximum air temperatures exceeding 28°C, we can conclude that mean climate changes are unlikely to cause ambient-temperature-related failure of the conductor circuit.

However, the climate change scenarios will have an impact on the resistivity of the circuit. According to our calculations[7], the climate scenarios are likely to reduce the circuit rating (in MVA) by 0.25% - 1% in summer and autumn, 0.3% - 0.7% in winter and 0.29% - 0.6% in spring. While these are not large changes, they do add additional restrictions on the circuit over and above those already planned for.

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[6] Faxed document from R. Blackburn – received 5 March 2005.

[7] Using the WEL Networks 33kV line rating calculator.

In summary, the Hamilton City electricity infrastructure distribution system appears to be very robust to mean climate change impacts. The City's physical infrastructure is well specified and designed to accommodate both growing loads and physical weather-related events. Hamilton's institutional capability in WEL Networks is also in excellent shape to address any climate-change related impacts.

5.4 Air quality

Although weather conditions in Hamilton do not encourage extreme air pollution, future climatic conditions may alter emissions and thus exacerbate health impacts. Three types of air pollutants are examined in CLINZI: particles less than 10 microns in size (PM_{10}), which are the main air quality parameter of concern in Hamilton (R. Jones pers. comm., Wilton 2005), carbon monoxide (CO), and nitrogen oxides (NO_X). Each of these can have adverse impacts on ecosystem and human health. Human health impacts are assessed in the following section.

Daily time series of PM_{10}, CO, NO, and NO_2 measured in Hamilton were acquired from Environment Waikato's regional monitoring database (1995). All air pollution components vary seasonally, with peaks in winter months.

Regression analysis (see Appendix E) suggests PM_{10} concentrations are a nonlinear, increasing function of the number of heating degree days (calculated over a 24-hour period at a balance point temperature of 14°C). PM_{10} concentrations tend to decrease with the amount of rainfall in a month. Particulate matter increases in May, as the cold season sets in, and decreases in August, as the cold season eases. Through all of its significant variables, this model reflects the increased levels of PM_{10} concentrations during cold weather, when the number of heating degree-days increases. This points to the well-known primary source of PM_{10}: emissions from heating, especially from wood fuel.

The estimated equation for CO (Appendix E) indicates the level of carbon monoxide varies positively with the number of cold days (as represented by HDD24_14) and negatively with the log of average wind speed. No time trend or seasonality have been detected for CO. However, the model shows increased levels of CO concentrations during cold weather, when the number of heating degree-days increases, which most likely implicates heating sources in CO generation.

A model of the influence of climatic variables on NO per capita included variables for average wind speed, monthly mean maximum temperature, and the autumn season. Concentrations of NO vary seasonally (weakly significant), insofar as they are higher in the autumn.

The PM_{10} forecasts show the most differentiation of all the air pollution models between climate change scenarios. Projections of PM_{10} under climate scenarios are similar to the base-case scenario, with no distinguishable temporal trend but strong seasonal cycles (Figure 8). The highest emissions occur in the base-case scenario, followed by S1, then, S3, then S2, then S4. In other words, due to increased temperatures, PM_{10} emissions decline most under the extreme climate change scenarios as a result of reduced need for heating. Calls for improved housing standards, including better insulation and increased use of double-glazed windows, may contribute to quality improvements of residences in terms of dryer, warmer homes. This could further reduce the need for heating, regardless of the temperature and precipitation trends, and thereby decrease the need to use home heating sources.

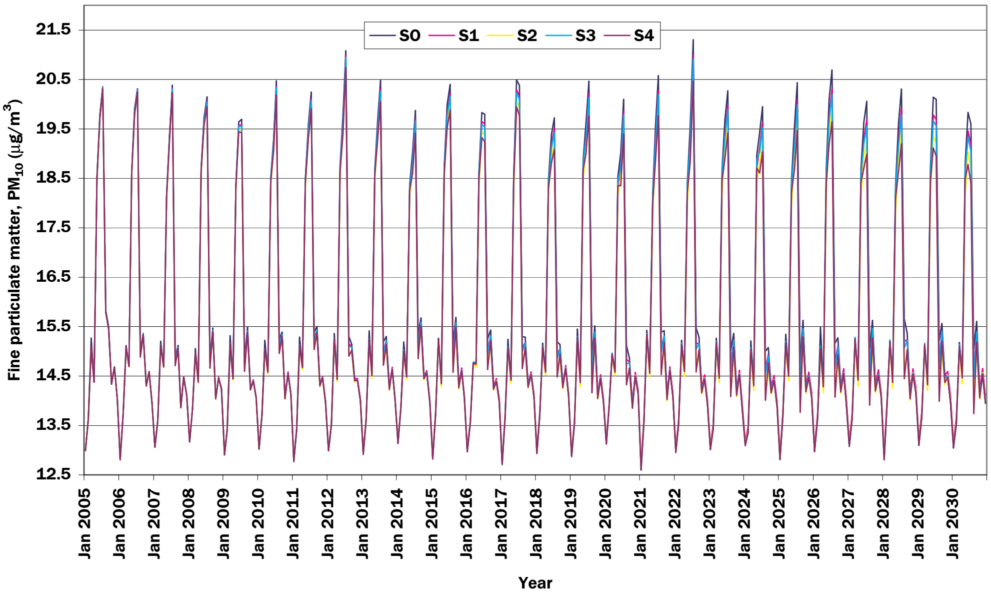

Figure 8: Projections of fine particulate matter (PM$_{10}$), 2005–2030

There is little differentiation between the different climate scenario projections for the carbon monoxide emission scenarios, though the degree of differentiation increases somewhat through time, starting around 2010. CO emissions exhibit a smoother seasonal cycle than those for PM$_{10}$; the same cycle occurs with minima in summer and maxima in winter. The amplitude remain consistent throughout the 2005–2030 time series, and there is no temporal shift through this period.

Similar to other air pollutants, the amplitude of NO emissions remains the same under base case and climate change scenarios, and there is no temporal shift from 2005–2030. The same seasonal cycle is retained throughout the projection period. Emissions maxima occur in the autumn and winter, with a primary peak in May and a secondary one in July.

Overall, changes in average temperature and precipitation may play a small role in emissions of air pollutants in Hamilton. However, to the extent that climate change contributes to more weather instability – with greater likelihood of extreme events, wind gusts, and windier conditions overall – future conditions may result in fewer opportunities for air pollutants to concentrate over the City. Increasing wind may actually help curb air quality problems from climate change. From the projections run in this study, it seems unlikely climate change alone would cause exceedances of any of New Zealand's ambient air-quality standards.

5.5 Public Health

Several studies suggest climate change is likely to induce higher incidences of many human health problems. For example, Elmwood (1995) suggests greater exposure to ultra-violet radiation will increase the frequency of cataracts, skin cancers, and sunburn. Also, as temperatures rise, summer smog is likely to cause more respiratory problems, particularly in the Auckland region (Woodward et al. 2001). Woodward (Woodward et al. 2001) points out that new health problems may result from both heat waves and the colonisation of mosquitoes that carry diseases like malaria and dengue fever. Pest eradication programmes are expensive and only partially successful, with many people reporting health complications from spraying. Warmer winters are expected to reduce the incidence of winter-related illnesses such as colds and flu and the need for open fires for heating, which contribute to air pollution.

Indirect health impacts are likely to occur as a result of floods and droughts. Heavy rain may disperse pathogens such as cryptosporidiosis by washing animal excreta containing the organism into water supplies (Ministry for the Environment 2001, p29). Drought periods will require the extraction of water from poorer quality sources with the resultant health risks.

To what extent are these suggested health impacts seen in recent morbidity and mortality data for Hamilton City? How will possible future climates exacerbate or ameliorate health conditions of the local population?

The data used to quantify relationships between climate and morbidity and mortality rates have been supplied by the New Zealand Health Information Service. The data consist of admissions to the regional hospital, and are classified by the primary cause of admission. Because only a fraction of people with health problems seek medical help, and only a fraction of these do so at the general hospital, the analysis is clearly underreporting morbidity rates in the region. Furthermore, not all admissions to the regional hospital are of people from Hamilton, so the results are biased to the extent that visitors seek medical help in Hamilton and residents seek help elsewhere. The lack of data prevents correction for this possible bias.

We grouped the morbidity data into five major classes: injuries, circulatory problems, respiratory problems, infections, and skin ailments. For mortality rates, the statistical analysis did not support treating causes of mortality separately from each other. Consequently, we report only on aggregate mortality rates here.

Morbidity

For each morbidity variable we estimated separate equations (Appendix F). Of particular note in these regression equations are the results for per capita injuries, respiratory health problems per capita, and mortality. Regression results for per capita injuries show that over time, the number of per capita injuries increases, though at a low rate, and increases with the number of rainless days. These results are consistent with observations that the tendency for people to seek medical attention for injuries is increasing and that the number of injuries increases with more opportunities for outdoor activities (as inferred from an increase in rainless days).

The results for the respiratory illness equations have been derived in a two-stage least squares regression, because one of the explanatory variables of the model – the air quality indicator PM_{10} – is present in the regression equation in squared form, and PM_{10} is itself a function of climatic variables and seasonal change. Particulate matter (PM_{10}) concentrations are a nonlinear, increasing function of the number of heating degree days (calculated over a 24-hour period at a balance point temperature of 14°C). PM_{10} concentrations tend to decrease with the amount of rainfall in a month. Hospitalisation for respiratory ailments per capita increase over time and increase nonlinearly with increases in PM_{10}.

For all morbidity indicators climate change scenarios makes no difference. That is, under the assumption that the future climate is like the past and that past trends in hospitalisation for injuries persist, then morbidity rates will continue to fluctuate seasonally and to increase slightly over the simulated 30-year time horizon. Furthermore, comparisons for selected years between the base case and scenarios reveal virtually indistinguishable dynamics. Results suggest that morbidity will predominantly be affected by past trends and seasonal fluctuations, but not by climate change.

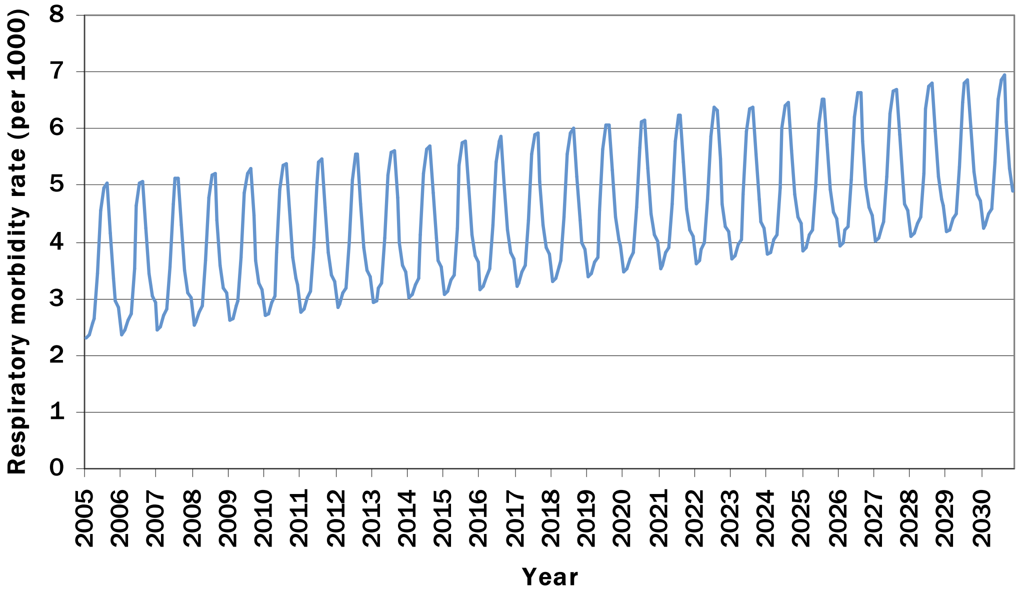

Figure 9: Projected respiratory morbidity rate for the base-case scenario, 2005–2030

Amplitude of seasonal fluctuations also remains largely unchanged over time – if there is no climate change or even if the more extreme climate change scenarios postulated above (S2 or S4) eventuates.

Except for circulatory morbidity, all results show increasing trends. Similar to the findings about changes in injuries, circulatory morbidity demonstrates clear seasonal fluctuations. However, circulatory morbidity rates show no discernable trend and remain, in the long term, around three cases per 1000. That pattern remains virtually unaffected by climate change.

Mortality

Our regression model for mortality finds an overall decline of mortality rates through time, but a persistent, statistically significant seasonal signal (Appendix F). Seasonality by itself explains nearly 30% of the variation in the data. Consistent with the literature, there are nonlinear relationships between increases in mean temperatures and increases in mortality rates. However, no impacts of daily extreme temperatures on mortality rates were found. The absence of clearly discernible heat or cold thresholds from our analysis is in large part due to the small number of low or high temperatures on record, none of which are sufficiently extreme to trigger increases in mortality rates. Nonetheless, regression results indicate that prolonged cold spells (events with three or more days below 0^{o}C) do tend to increase mortality rates.

For the purposes of this section, we compare the usual suite of scenarios with a hypothetical "extremes" climate change case[8]. The assumptions for this hypothetical case are well outside the extremes reported for CSIRO and Hadley Centre climate models and were chosen to explore the implications of unprecedented variation in climate conditions.

The morbidity rates discussed above all show notable seasonal fluctuations and long-term increases. In contrast, mortality rates – though also exhibiting marked seasonal fluctuations – tend to decline slightly over time **(**Figure 10**)**. The differences in the behaviour of these two sets of health indicators may largely be attributable to a combination of changes in behaviours and health care provision. While improvements in care tend to induce demand for care, they tend also to reduce mortality rates. However, even though mortality rates do decline, the extent of that decline is rather small (compared with the extent by which some of the morbidity rates increase).

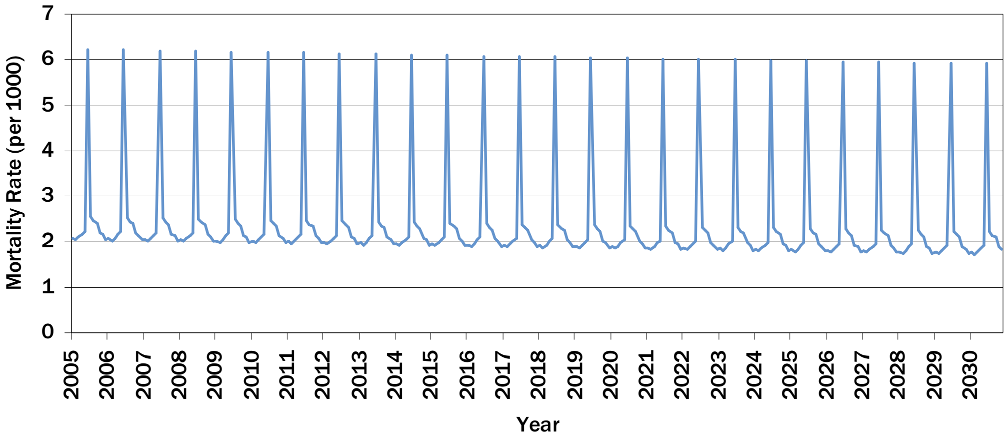

Figure 10: Projected mortality rates for the base-case scenario, 2005–2030

In summary, the results indicate that seasonal fluctuations and annual trends are likely to be far more relevant in explaining possible future variations in morbidity and mortality than are climate parameters. However, the annual trend embeds information about changes in behaviours, improvements in healthcare (such as early detection, education, patient care), and improvements in and diffusion of technology (from ointments for protection of skin against UV radiation to inhalers for treatment of asthma or proliferation of air conditioning to reduce impacts of heat), all of which counteract any of the adverse health impacts associated with longer term climatic conditions. Reducing vulnerability to climate change will require maintaining the changes in behaviours and improvements in health care and technology at rates comparable to those observed in the past.

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[8] In this hypothetical extreme case the deviations from past climate are assessed as a gradual increase in temperatures by 5°C between 1990 and 2030, which is uniformly applied across the seasons. Additionally, we assume precipitation will decline between 1990 and 2030 by 24% on average in summer months, by 10% in autumn, and by 5% in spring, while precipitation in winter is assumed to increase by 12%.

5.6 Integration of impacts

The emphasis of this project was on the integration of climate and demographic changes on infrastructure in Hamilton City and on examining these impacts with a common framework.

Using the results of this research, it is possible to speculate how impacts in one sector could influence another sector. Table 7 shows the impacts of gradual climate change across sectors. Reading the table horizontally shows the impacts of one sector on another. Reading the table vertically shows possible impacts on that sector from all the systems analysed.

As can be seen, the impacts of one infrastructure system in many cases could also negatively impact on the performance of other infrastructure systems. The energy infrastructure systems appear to impact the widest range of other infrastructure sectors, followed by transport. That is, these two infrastructure systems have the largest number of impacts cutting across sectors.

Reading the table vertically indicates that public health followed by air quality are the sectors most effected by other sectors. These interactions are important because they have the potential to magnify any negative impacts caused by climate change alone in a sector. For example, the water consumption analysis found that climate change generally has limited impact on water use. If this analysis, however, had the resources to examine conjunctive impacts due to water quality, energy supply and other impacts, negative impacts of climate change may have been found. Unfortunately, it was not possible under the time, budget and data constraints of this project to quantify all of these interactions.

Table 7: Integration of infrastructure impacts

	Water	Transport	Energy	Air quality	Public health
Water	Little impact on water consumption, possible increase in turbidity – increased treatment costs?	NA	Possible increase in energy use for water treatment if increases in turbidity require larger energy inputs into treatment.	NA	Little impact on water demand potential for health impacts if water supply disrupted by extreme events.
Transport	NA	Little impact on trips. Possible increase in road repair costs – consequent increase in congestion?	NA	Increased trips due to population pressure likely to increase traffic-based atmospheric pollutants.	Increased air emissions from increased traffic provide potential for increased health impact.
Energy	Disruption of electricity supply could disrupt water supply and treatment.	Disruption of electricity supply could disrupt traffic signals – unlikely except in extreme events.	Extension of summer conditions into autumn means less electricity demand and reduced use of wood burning stoves. Increased penetration of AC in summer increases summer peak	Potential for less emissions from wood burning stoves in autumn.	Disruption of electricity supply could disrupt public health provision. Potential decrease in air emissions-related public health issues in autumn.
Air quality	Pollution to acid rain impacts on acidity of water supply	NA	NA	Little impact from gradual climate change on air quality.	Potential decrease in air emissions-related public health issues in autumn.
Public health	NA	NA	NA	NA	Little impact from gradual climate change on public health.

6 Recommendations and conclusions

As a result of this study, we are able to make several recommendations relating to sectoral policies as well as data requirements and areas for future research.

6.1 Policies

6.1.1 General

Across all infrastructure systems, policy makers would be wise to continue to focus on demographics when planning for system upgrades. Many of the infrastructure sectors we investigated demonstrated greater responsiveness to population changes than changes in gradual climate change. Any future planning decisions should be sensitive to climate change, but not driven by it.

6.1.2 Water treatment

With respect to water treatment, while modest decreases in water clarity would have negligible impact on water-treatment costs, city planners should keep such changes in mind when making equipment investment decisions. This thinking also extends beyond turbidity and water treatment, in that some of the more subtle impacts of climate change – such as water clarity – may occur where cities face unforeseen impacts on infrastructure capabilities. Hamilton City would be wise to consider what other factors, beyond turbidity, influence the costs and/or effectiveness of water treatment and ascertain whether changes in climate could lead to changes in these factors, which in turn could lead to costly changes in equipment or process needs.

6.1.3 Electricity use

In addition to planning for changes in Hamilton City demographics, electricity distribution and retail companies need to consider the impact of changes in ambient temperatures on circuit resistivity. The New Zealand electricity market is highly competitive. Changes in operating costs – even small increases – could impact on the company's profitability and competitiveness.

6.1.4 Air quality

Adaptation to changes in air quality, especially in terms of public health, can occur on several fronts including:

- Legislative options: emission controls, traffic restrictions
- Technical options: improved public transport, improved insulation, higher energy efficiency, catalytic converters, smoke stacks
- Educational/advisory: pollution warning
- Cultural and behavioural; carpooling.

All these strategies are important in Hamilton. In addition, the local context requires a shift in requirements and attitudes to standards for housing construction and the approach to home heating.

6.1.5 Public health

Reducing vulnerability to climate change will require both the public and health providers to maintain the changes in behaviours and improvements in health care and technology at rates comparable to those observed in the past.

6.2 Data needs and future research

As with all research projects, the scope of CLINZI has been dictated to a large extent by the availability of data. More extensive collection of time series data for each of the relevant infrastructure systems and services would enable research expansion in three aspects: temporal detail, spatial scope, and climate extremes. Rather than modelling climate changes and impacts on infrastructure using a monthly time step, it is necessary to conduct future research at a daily level. This will allow greater connection among climate events, infrastructure impacts, and infrastructure management.

The spatial scope of this study was limited because of resource constraints. However, future research needs to expand the study boundary to include the wider infrastructure systems that feed Hamilton City. For example, it is important to consider not only the electricity distribution system within Hamilton City, but also the electricity generation and supply systems that feed the city. These physical structures, which lie outside the city boundary, are also vulnerable to changes in climate, and this vulnerability needs to be considered an integral part of any future research on climate change impacts on Hamilton City.

The relevance of this study has also been limited by investigating only gradual climate changes. Many infrastructure systems are designed on the basis of accommodating extreme events and future research on climate change impacts on infrastructure must include an allowance for changes in the frequency and intensity of extreme weather events.

7 References

Amato, A. D., M. Ruth, P. Kirshen, and J. Horwitz. 2005. Regional energy demand responses to climate change: methodology and application to the commonwealth of Massachusetts. Climatic Change **71**(1):175-201.

Bloomfield, J., M. Smith, and N. Thompson. 1999. Hot Nights in the City: Global Warming, Sea-Level Rise and the New York Metropolitan Region. Environmental Defense Fund, Washington, D.C.

Boustead, I., and B. Yaros. 1994. Electricity supply industry in North America. Resources, Conservation, Recycling **12**(3–4):121–134.

Cohen, S. J. 1996. Integrated regional assessment of global climatic change: Lessons from the Mackenzie Basin Impact Study (MBIS). Global and Planetary Change **11**(4):179.

Cohen, S. J. 1997. What if and so what in northwest Canada: Could climate change make a difference to the future of the Mackenzie basin? Arctic **50**(4):293.

Elwood, M., and Z. The Royal Society of New. 1995. Health Effects of Increases in Ultraviolet Radiation. Pages 19 *in* Industry research priorities for climate change. The Royal Society of New Zealand, Wellington.

Energy Efficiency and Conservation Authority. 2004. Draft Energy End-Use Data Base. Energy Efficiency and Conservation Authority, Wellington, New Zealand.

Fitzharris, B., and C. Garr. 1996. Climate, water resources and electricity. Pages 263–280 *in* W. Bouma, G. Peaman, and M. Manning, editors. Greenhouse — coping with climate change.

Gillet, N. P., and W. J. Thompson. 2003. Simulation of Recent Southern Hemisphere Climate Change. Science **302**:273–275.

Houghton, J. T., Y. Ding, D. J. Griggs, M. Noguer, P. J. van der Linden, X. Dai, K. Maskell, and C. A. Johnson, editors. 2001. Climate Change 2001: The Scientific Basis. Cambridge University Press, Cambridge.

Huang, G. H., S. J. Cohen, Y. Y. Yin, and B. Bass. 1998. Land resources adaptation planning under changing climate — a study for the Mackenzie Basin. Resources Conservation and Recycling **24**(2):95.

IPCC, T. I. P. o. C. C. 2001. Climate Change 2001: Working Group II: Impacts, Adaptation and Vulnerability. Available at http://www.grida.no/climate/ipcc_tar/wg2/index.htm.

Kirshen, P. H., M. Ruth, W. Anderson, T. R. Lakshmanan, S. Chapra, W. Chudyk, L. Edgers, D. Gute, M. Sanayei, and R. Vogel. 2004. Climate's Long-term Impacts on Metro Boston, Final Report to the US EPA. Office of Research and Development, Washington, D.C.

Koteen, L., J. Bloomfield, T. Eichler, C. Tonne, R. Young, H. Poulshock, and A. Sosler. 2001. Hot Prospects: The Potential Impacts of Global Warming on Los Angeles and the Southland. Environmental Defense Fund, Washington, D.C.

Lakshmanan, T., and W. Anderson. 1980. Residential energy demand in the United States: a regional econometric analysis. Regional Science and Urban Ecology **10**:371–386.

Ministry for the Environment. 2001. Climate Change Impacts on New Zealand. ME396, Ministry for the Environment, Wellington. Available at http://www.mfe.govt.nz/publications/climate/impacts-report-jun02.pdf.

Office of Science and Technology, P. 1997. Climate change: state of knowledge. Executive Office of the President, Washington, D.C.

Patterson, M. G., G. W. McDonald, N. E. Golubiewski, V. E. Forgie, and N. A. Jollands. *in press*. Climate change impacts on regional development and sustainability: An analysis of New Zealand regions. Pages 83–110 *in* M. Ruth, editor. Smart growth and climate change: Regional development, infrastructure and adaptation. Edward Elgar Publishing, Cheltenham, UK.

Penney, A. C. 2001. Climate Database (CLIDB) user's manual. 5th edition National Institute of Water and Atmospheric Research, 175.

Rosenzweig, C., W. Solecki, C. Paine, V. Gornitz, E. Hartig, K. Jacob, D. Major, P. Kinney, D. Hill, and R. Zimmerman. 2000. Climate Change and a Global City: An Assessment of the Metropolitan East Coast Region. U.S. Global Change Research Program. Available at http://metroeast_climate.ciesin.columbia.edu/.

Ruth, M., K. Donaghy, and P. Kirshen. 2005. Climate Change and Variability: local impacts and responses. Edward Elgar, Cheltenham.

Sailor, D. J., and J. R. Munoz. 1997. Sensitivity of electricity and natural gas consumption to climate in the USA -- methodology and results for eight states. Energy **22**(10):987–998.

Schmandt, J., and J. Clarkson. 2005. The regions and global warming: Impacts and response strategies. Oxford University Press, New York.

Statistics New Zealand. 2000. Subnational population projections (1996 base - 2021). Available at www.stats.govt.nz.

Vogel, R. M., and A. L. Shallcross. 1996. The moving blocks bootstrap versus parametric time series models. Water Resources Research **32**(6):1875–1882.

Wilton, E. 2005. Air Quality Monitoring 2004. Document #979624, Environment Waikato, Hamilton, 32. Available at http://www.ew.govt.nz/publications/index.htm?pubcategory=4.

Woodward, A., S. Hales, and N. de Wet. 2001. Climate change: potential effects on human health in New Zealand. ISBN 0-478-24043-0, Ministry for the Environment, Wellington, N.Z. Available at www.climatechange.govt.nz.

Appendix A

Table 8: Monthly Climate Variables used in regression analysis

Variable	Description
AvgWindSpd	Monthly average wind speed (mps)
CDD24 X	Total cooling degree days during month based on 24hr mean temps, using X°C as the threshold temp.
CDDL X	Total cooling degree days during month based on daylight mean temps, using X°C as the threshold temp.
DaysAbove26	Number of days during the month with max temp above 26°C
DaysBelow0	Number of days during the month with min temp below 0°C
DaysNoRain	Number of days during the month with no rainfall
DaysRainAbove20	Number of days during month with rainfall above 20mm
HDD24 X	Total heating degree days during month based on 24hr mean temps, using X°C as the threshold temp.
HDDL X	Total heating degree days during month based on daylight mean temps, using X°C as the threshold temp.
MaxMean	Monthly mean maximum daily temperature (°C)
MaxRainlessStk	length, in days, of the longest period with no rainfall (counting streaks that begin before the month in question)
Mean24Temp	Monthly mean of daily mean 24hr temps (calculated as a daylight-dependent weighted average of min and max temps for each day) (°C)
MeanLgtTemp	Monthly mean of daily mean daylight temps (calculated as .71*maxtemp + .29*mintemp for each day) (°C)
MinMean	Monthly mean minimum daily temperature (°C)
MonthRain	Total monthly rainfall (mm)
MaxXDayRain	Maximum total rainfall during a X-day period during the month (values generated for X = 1, 3, 7, and 10)
maxtemp	Maximum max temp during month
mintemp	Minimum min temp during month
streakabove26	Longest streak of days at or above 26 degrees C
streakbelow0	Longest streak of days at or below 0 degrees C
streaks26_3day	Number of 3-day streaks at or above 26 degrees C
streaks0_3day	Number of 3-day streaks at or below 0 degrees C
MMrain20	Total number of millimetres of rain above 20 per day during the month (similar to heating/cooling degree days)

Appendix B

Table 9: Regression results for the water consumption model

Prais-Winsten AR(1)					
Observations	108	F(16,91)	437.63	R^2	0.9872
Durbin-Watson (original)	1.313540	Root MSE	.04147	Adjusted R^2	0.9849
Durbin-Watson (trans)	2.002040	Rho	.4220185		

Source	SS	df	MS
Model	12.0427384	16	.752671149
Residual	.156508331	91	.001719872
Total	12.1992467	107	.114011652

Parameter	Coefficient	Std. Err	t	P>|t|	[95% Conf.	Interval]
January	.027	.020	1.31	0.192	-.0137327	.0674616
February	.052	.024	2.17	0.033	.0043646	.0987913
March	-.024	.022	-1.10	0.273	-.0674249	.0192857
April	-.16	.022	-7.10	0.000	-.2041987	-.1149456
May	-.17	.026	-6.60	0.000	-.2251367	-.1210215
June	-.13	.032	-4.25	0.000	-.1975199	-.0716417
July	-.16	.034	-4.62	0.000	-.2256852	-.0899886
August	-.13	.032	-4.07	0.000	-.1916858	-.0658601
September	-.13	.027	-4.89	0.000	-.1826185	-.0770603
October	-.11	.022	-5.13	0.000	-.1560153	-.0689511
November	-.017	.018	-0.95	0.346	-.0517488	.0183305
streaks26_~y	.0026	2.48	0.015	.001277	.0114784	
max3dayrain	-.00082	.00024	-3.41	0.001	-.0013038	-.0003439
meanlgttemp	.011	.0036	3.24	0.002	.0044371	.0185449
maxrainles~k	.00076	5.46	0.000	.0026223	.0056256	
daysnorain	.0075	.0014	5.35	0.000	.0046864	.0102221
_cons	9.11	.078	116.71	0.000	8.952278	9.262295

Table 10 Regression results for the turbidity model (water quality proxy)

Prais-Winsten AR(1)					
Observations	46	F(13,32)	4.15	R^2	0.6275
Durbin-Watson (original)	1.543525	Root MSE	.73017	Adjusted R^2	0.4762
Durbin-Watson (trans)	1.832980	Rho	.2282434		

Source	SS	df	MS
Model	28.745592	13	2.21119938
Residual	17.0606772	32	.533146164
Total	45.8062692	45	1.01791709

Parameter	Coefficient	Std. Err.	t	P>|t|	[95% Conf. interval]	
lnorain	-2.29	.71	-3.21	0.003	-3.747766	-.8395709
daysbelow0	-.351	.11	-3.13	0.004	-.5798261	-.1223972
January	.71	.58	1.23	0.226	-.4639498	1.889535
February	1.00	.57	1.76	0.088	-.1576345	2.148719
March	.56	.60	0.94	0.356	-.659519	1.780505
April	.69	.62	1.11	0.275	-.5721525	1.946249
May	.0065	.54	0.01	0.991	-1.099788	1.112819
June	1.86	.61	3.05	0.005	.617918	3.106892
July	2.29	.83	2.75	0.010	.5954796	3.982343
August	1.01	.73	1.38	0.178	-.4847506	2.505499
September	.86	.54	1.59	0.122	-.243922	1.968222
October	-.14	.54	-0.26	0.797	-1.246565	.9653507
November	-.128	.48	-0.27	0.792	-1.102655	.8474743
constant	9.26	2.05	4.52	0.000	5.084173	13.43767

Appendix C

Table 11: Regression results for the model of trips per capita

Prais-Winsten AR(1)					
Observations	30	F(13,16)	221.43	R^2	0.9945
Durbin-Watson (original)	0.644665	Root MSE	.3931	Adjusted R^2	0.9900
Durbin-Watson (trans)	2.420853	Rho	.7513345		

Source	SS	df	MS
Model	444.836235	13	34.2181719
Residual	2.47250402	16	.154531501
Total	447.308739	29	15.4244393

Parameter	Coefficient	Std. Err.	t	P>|t|	[95% Conf. Interval]	
Streaks26_~y	-.75	.20	-3.73	0.002	-1.175007	-.3239249
mmrain20	-.014	.0058	-2.41	0.028	-.0260909	-.0016578
January	-.34	.83	-0.41	0.684	-2.091838	1.408226
February	.99	.46	2.15	0.047	.0136781	1.964481
March	.93	.41	2.26	0.038	.0577767	1.800827
April	-.42	.43	-0.96	0.350	-1.330324	.4994569
May	.47	.42	1.10	0.286	-.4276125	1.358376
June	-.13	.43	-0.31	0.763	-1.039342	.7761736
July	.18	.42	0.43	0.674	-.7184751	1.082397
August	.36	.42	0.87	0.395	-.5172248	1.244125
September	.25	.40	0.63	0.539	-.6000006	1.104174
October	.58	.35	1.65	0.119	-.1651166	1.318777
November	1.39	.28	4.91	0.000	.792538	1.995675
constant	28.84	.33	86.35	0.000	28.12808	29.54399

Table 12: Regression results for the model of cost of repairs per capita

Prais-Winsten AR(1)					
Observations	61	F(13,47)	2.39	R^2	0.3982
Durbin-Watson (original)	1.716062	Root MSE	0.00868	Adjusted R^2	0.2317
Durbin-Watson (trans)	1.893188	Rho	0.1840489		

Source	SS	df	MS
Model	.002345061	13	.000180389
Residual	.003544374	47	.000075412
Total	.005889435	60	.000098157

Parameter	Coefficient	Std. Err.	t	P>t	[95% Conf.	Interval]
mmrain20	.00014	.000076	1.81	0.076	-.000015	.0002886
maxrainles~k	-.00046	.00019	-2.44	0.019	-.0008336	-.0000795
January	-.013	.0060	-2.13	0.039	-.024851	-.000694
February	-.021	.0071	-2.95	0.005	-.0350643	-.0066113
March	-.020	.0059	-3.43	0.001	-.0319831	-.0083478
April	-.014	.0066	-2.14	0.038	-.0275562	-.0008431
May	-.025	.0066	-3.71	0.001	-.0380165	-.0112809
June	-.013	.0061	-2.07	0.044	-.025038	-.0003466
July	-.019	.0062	-3.03	0.004	-.031383	-.0063328
August	-.013	.0077	-1.66	0.104	-.0283091	.0027321
September	-.017	.0066	-2.59	0.013	-.0304666	-.0038045
October	-.011	.0056	-1.94	0.059	-.0222095	.0004135
November	-.015	.0062	-2.50	0.016	-.0279485	-.0030477
_cons	.032	.0056	5.71	0.000	.0205848	.0429813

Appendix D

Table 13: Electricity demand regression results

Yule-Walker Estimates			
SSE	1.48247472	DFE	161
MSE	0.00921	Root MSE	0.09596
SBC	-255.13812	AIC	-312.51107
Adj R-Square	0.9508	R-Squared	0.9846
Log Likelihood	-847.93452	Observations	179
Durbin-Watson	1.8297		

Parameter	DF	Coefficient	Standard Error	t Value	Approx Pr > |t|
Intercept	1	2.56	0.12	21.54	<.0001
HDD24_15	1	0.0021	0.00038	5.41	<.0001
Workday_Percent	1	1.01	0.18	5.73	<.0001
year_dummy	1	0.0099	0.00032	31.40	<.0001
January	1	-0.15	0.030	-5.03	<.0001
February	1	0.20	0.036	5.45	<.0001
March	1	0.25	0.041	6.15	<.0001
April	1	0.24	0.045	5.37	<.0001
May	1	0.23	0.14	1.61	0.1097
June	1	0.89	0.084	10.65	<.0001
July	1	0.54	0.13	4.03	<.0001
August	1	0.84	0.078	10.77	<.0001
September	1	0.52	0.060	8.69	<.0001
October	1	0.28	0.043	6.62	<.0001
November	1	0.21	0.031	6.78	<.0001
HDD_15_May	1	0.0026	0.0011	2.40	0.0177
HDD_15_July	1	0.0021	0.00068	3.12	0.0022

Appendix E

Table 14: Regression results for the fine particulate matter (PM_{10}) model, using the square of PM_{10} as the independent variable

Parameter	Coefficient	Std. Error	Z	Pr>z	95% Confidence Interval	
HDD24_14_sq	.0067	.0011	6.29	0.000	.0045905	.0087466
Monthrain	-.49	.15	-3.17	0.002	-.791543	-.1868466
January	-38.20	31.97	-1.19	0.232	-100.8648	24.45763
February	-18.64	32.75	-0.57	0.569	-82.82886	45.54969
March	23.73	31.95	0.74	0.458	-38.88171	86.34554
April	-1.55	34.13	-0.05	0.964	-68.43341	65.33646
May	73.40	32.50	2.26	0.024	9.691753	137.1001
June	-2.23	38.04	-0.06	0.953	-76.79599	72.3301
July	-30.35	44.49	-0.68	0.495	-117.5529	56.86247
August	-120.17	39.19	-3.07	0.002	-196.9828	-43.36266
September	-24.22	31.15	-0.78	0.437	-85.27051	36.82164
October	-16.01	30.69	-0.52	0.602	-76.15195	44.13746
November	8.21	30.09	0.27	0.785	-50.75271	67.17702
Constant	245.33	27.17	9.03	0.000	192.0733	298.5906

Table 15: Regression results for the carbon monoxide (CO) model

Yule-Walker					
Observations	86			R^2	0.7141
Durbin-Watson (original)	0.8642	Root MSE	0.12280	Adjusted R^2	0.5106
Durbin-Watson (trans)	1.995				

Parameter	DF	Coefficient	Standard Error	t Value	Approx Pr > |t|
Intercept	1	0.43	0.089	4.77	<.0001
LogAvWindSpd	1	-0.42	0.20	-2.10	0.0385
HDD24_14	1	0.0025	0.00032	8.02	<.0001

Table 16: Regression results for the nitric oxide (NO) per capita

Yule-Walker					
Observations	28			R2	0.84
Durbin-Watson (original)	1.94	Root MSE	0.000064	Adjusted R2	0.82
Durbin-Watson (trans)	1.91				

Parameter	DF	Coefficient	Standard Error	t Value	Approx Pr > |t|
Intercept	1	0.0010	0.00014	7.2	<.0001
MaxMean	1	-0.000029	0.0000073	-3.93	0.0008
logWind	1	-0.00032	0.000099	-3.24	0.0039
summer	1	0.000080	0.000068	1.19	0.25
fall	1	0.00011	0.000054	1.93	0.067
winter	1	0.000018	0.000044	0.4	0.69

Appendix F

Table 17: Regression results for per capita injuries

Prais-Winsten AR(1)					
Observations	192	F(14,178)	531.15	R^2	0.5178
Durbin-Watson (original)	0.866596	Root MSE	0.00028		
Durbin-Watson (trans)	2.237482	Rho	0.5749231		

Parameter	Coefficient	Std. Err.	t	P>t	[95% Conf.	Interval]
time	8.87e-06	8.26e-07	10.74	0.000	7.24e-06	.0000105
daysnorain	.0000101	4.81e-06	2.09	0.038	5.55e-07	.0000196
January	-.0001607	.0000936	-1.72	0.088	-.0003455	.000024
February	.000159	.0001228	1.30	0.197	-.0000833	.0004014
March	.0002222	.0001159	1.92	0.057	-6.49e-06	.000451
April	-.0000518	.0001222	-0.42	0.672	-.0002929	.0001893
May	-.0001526	.0001178	-1.30	0.197	-.0003852	.0000799
June	-.0002807	.0001182	-2.37	0.019	-.0005139	-.0000475
July	-.000455	.0001178	-3.86	0.000	-.0006875	-.0002224
August	-.0002159	.0001172	-1.84	0.067	-.0004472	.0000154
September	-.0001885	.000113	-1.67	0.097	-.0004115	.0000345
October	-.0000889	.0001086	-0.82	0.414	-.0003032	.0001254
November	.0001284	.0000887	1.45	0.150	-.0000466	.0003034
constant	.0029545	.0001441	20.51	0.000	.0026703	.0032388

Table 18: Regression results for circulatory health problems per capita

Prais-Winsten AR(1)					
Observations	192	F(13,179)	15.89	R^2	0.1634
Durbin-Watson (original)	0.163251	Root MSE	0.00028		
Durbin-Watson (trans)	2.675609	Rho	.9163017		

Parameter	Coefficient	Std. Err.	t	P>t	[95% Conf.	Interval]
daysbelow0	.0000158	.0000102	1.55	0.123	-4.34e-06	.000036
January	-.0001712	.0000756	-2.26	0.025	-.0003203	-.000022
February	-.0001592	.0000996	-1.60	0.112	-.0003556	.0000373
March	-.000052	.0001048	-0.50	0.620	-.0002588	.0001548
April	.0000825	.0001216	0.68	0.498	-.0001574	.0003224
May	.0002755	.0001267	2.17	0.031	.0000255	.0005256
June	.00027	.0001319	2.05	0.042	9.84e-06	.0005302
July	.0003787	.0001318	2.87	0.005	.0001186	.0006389
August	.0003186	.0001219	2.61	0.010	.000078	.0005591
September	.0002608	.0001007	2.59	0.010	.0000621	.0004595
October	.0002421	.0000798	3.03	0.003	.0000846	.0003995
November	.0002136	.0000552	3.87	0.000	.0001047	.0003224
constant	.0027943	.0002423	11.53	0.000	.0023162	.0032724

Table 19: Regression results for respiratory health problems per capita

Equation	Obs	Parms	RMSE	"R-sq"	chi2	P
resppercap	66	13	.0004066	0.8374	351.01	0.0000
pm10sq	66	13	52.2648	0.6943	151.90	0.0000

Parameter	Coefficient	Std. Err.	z	P>z	[95% Conf Interval	
Time	6.50e-06	2.30e-06	2.82	0.005	1.99e-06	.000011
pm10sq	2.00e-06	9.59e-07	2.09	0.037	1.22e-07	3.88e-06
January	-.0004163	.0002473	-1.68	0.092	-.0009011	.0000684
February	-.0004086	.0002465	-1.66	0.097	-.0008918	.0000746
March	-.0003116	.0002493	-1.25	0.211	-.0008002	.0001769
April	-.0001759	.0002635	-0.67	0.504	-.0006923	.0003406
May	.0003413	.0002799	1.22	0.223	-.0002073	.0008899
June	.001351	.0002732	4.95	0.000	.0008156	.0018864
July	.0016988	.0002807	6.05	0.000	.0011485	.002249
August	.002094	.0002413	8.68	0.000	.0016211	.0025669
September	.0012427	.0002379	5.22	0.000	.0007764	.001709
October	.0005088	.0002355	2.16	0.031	.0000472	.0009704
November	.0000914	.0002351	0.39	0.697	-.0003693	.0005522
_cons	.0010436	.0004459	2.34	0.019	.0001697	.0019176

pm10sq						
HDD24_14_sq	.0066685	.0010602	6.29	0.000	.0045905	.0087466
monthrain	-.4891948	.1542621	-3.17	0.002	-.791543	-.1868466
January	-38.2036	31.97061	-1.19	0.232	-100.8648	24.45763
February	-18.63959	32.75023	-0.57	0.569	-82.82886	45.54969
March	23.73192	31.94631	0.74	0.458	-38.88171	86.34554
April	-1.54848	34.12559	-0.05	0.964	-68.43341	65.33646
May	73.39592	32.50273	2.26	0.024	9.691753	137.1001
June	-2.232946	38.04307	-0.06	0.953	-76.79599	72.3301
July	-30.34519	44.49452	-0.68	0.495	-117.5529	56.86247
August	-120.1727	39.18953	-3.07	0.002	-196.9828	-43.36266
September	-24.22444	31.14653	-0.78	0.437	-85.27051	36.82164
October	-16.00725	30.68664	-0.52	0.602	-76.15195	44.13746
November	8.212153	30.08467	0.27	0.785	-50.75271	67.17702
constant	245.332	27.17326	9.03	0.000	192.0733	298.5906

Durbin-Watson d-statistic = 1.51

Table 20: Regression results for infections per capita

Prais-Winsten AR(1)					
Observations	192	F(3,189)	677.87	R^2	0.4510
Durbin-Watson (original)	1.229486	Root MSE	0.00013		
Durbin-Watson (trans)	2.025194	Rho	0.3830764		

Parameter	Coefficient	Std.Err.	t	P>t	[95% Conf. Interval]	
hddl18	5.93e-07	1.77e-07	3.35	0.001	2.44e-07	9.41e-07
time	3.31e-06	2.66e-07	12.47	0.000	2.79e-06	3.84e-06
constant	.0003094	.0000288	10.76	0.000	.0002527	.0003661

Table 21: Regression results for skin diseases per capita

Prais-Winsten AR(1)					
Observations	192	F(14,178)	449.97	R^2	0.7278
Durbin-Watson (original)	1.509966	Root MSE	9.4e-05		
Durbin-Watson (trans)	2.045048	Rho	0.2444574		

Parameter	Coefficient	Std.Err.	t	P>t	[95% Conf. Interval	
Maxtemp	.0000105	5.10e-06	2.05	0.041	4.09e-07	.0000205
Time	3.36e-06	1.68e-07	20.05	0.000	3.03e-06	3.69e-06
January	.0000335	.0000229	1.46	0.145	-.0000116	.0000787
February	.0001333	.0000359	3.71	0.000	.0000625	.0002041
March	.0001136	.0000314	3.62	0.000	.0000517	.0001755
April	.0001016	.0000253	4.02	0.000	.0000517	.0001515
May	.0001014	.0000383	2.65	0.009	.0000258	.000177
June	.0001121	.0000505	2.22	0.028	.0000124	.0002117
July	.0001041	.0000516	2.02	0.045	2.25e-06	.0002059
August	.0000728	.0000522	1.40	0.165	-.0000301	.0001757
September	.0000632	.0000442	1.43	0.154	-.000024	.0001504
October	1.00e-05	.0000385	0.26	0.796	-.000066	.000086
November	.0000133	.0000278	0.48	0.634	-.0000415	.0000681
_cons	2.05e-06	.0001326	0.02	0.988	-.0002597	.0002638

Table 22: Regression results for mortality per capita

Prais-Winsten AR(1)					
Observations	168	F(15,153)	1790.70	R^2	0.5561
Durbin-Watson (original)	1.778329	Root MSE	0.00016		
Durbin-Watson (trans)	1.929921	Rho	0.0862144		

Parameter	Coefficient	Std. Err.	t	P>t	[95% Conf. Interval]	
Time	-1.02e-06	2.72e-07	-3.77	0.000	-1.56e-06	-4.87e-07
streaks0_3~y	.0000273	.0000159	1.72	0.087	-4.01e-06	.0000586
cdd2422sq	1.30e-06	3.38e-07	3.84	0.000	6.29e-07	1.96e-06
January	.0000182	.000064	0.28	0.777	-.0001084	.0001447
February	-.0000173	.0000601	-0.29	0.774	-.000136	.0001014
March	.0000389	.0000663	0.59	0.558	-.0000921	.0001699
April	.0001171	.0000665	1.76	0.080	-.0000143	.0002486
May	.0001773	.0000625	2.84	0.005	.0000539	.0003007
June	.0003713	.0000792	4.69	0.000	.0002148	.0005278
July	.0004535	.000076	5.97	0.000	.0003034	.0006036
August	.0003996	.000089	4.49	0.000	.0002237	.0005755
September	.0003582	.0000642	5.58	0.000	.0002313	.000485
October	.0001498	.0000659	2.27	0.024	.0000196	.0002801
November	.000102	.0000629	1.62	0.107	-.0000222	.0002262
_constant	.0016359	.0000563	29.07	0.000	.0015247	.0017471