Statistical Analysis of the Spatial and Temporal Distribution of Acid Deposition in the West Midlands, England, United Kingdom

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Abstract

The burning of high sulfur coal during the Industrial Revolution of England resulted in air quality deterioration. Anthropogenic emissions are linked to health problems and environmental degradation. The implementation of environmental emission control legislation of the 1970s resulted in a significant decrease in sulfur dioxide (SO_2) and nitrogen oxide (NO_x) emissions.

Acid deposition, as a result of industrialization, spatially and temporally varies throughout the West Midlands of England. This study seeks to quantify the effects of acid deposition as a result of the Industrial Revolution of the West Midlands using lead-lettered marble gravestone corrosion as a proxy for environmental degradation. Prior to the implementation of environmental legislation corrosion values were 0.78 mm/100yrs and following legislation values decreased to 0.54 mm/100yrs indicating the efficacy of environmental clean-up efforts.

Within individual cemeteries considerable variability exists. Factors that may contribute to this variability include: tree cover, orientation of stones, algae/lichen cover, gravestone texture, and local elevation differences. Statistical analysis of cemetery variables indentified tree cover, gravestone texture, gravestone color (algae/lichen cover), and local elevations differences to be significant with p-values ≤ 0.5. Tree cover and gravestone texture were used to adjust corrosion measurements. Adjusted cemetery corrosion rates mapped in ArcGIS® suggest spatial and temporal variability across the study area. Areas associated with high industrial and/or residential activity correlate to high corrosion rates.

Table of Contents

Acknowledgements i
Abstract iii
Table of Contents iv
List of Tables vi
List of Figures vii
1. Introduction 1
2. Background 5
    2.1 Industrialization History of the West Midlands 5
    2.2 Acid Precipitation Associated with Industrialization 12
    2.3 Carbonate Corrosion Measurement Techniques 13
    2.4 Assessment of Marble Monument Corrosion 15
3. Methods 19
    3.1 Spatial Distribution of Cemetery Selection 19
    3.2 Marble Gravestone Selection 19
    3.3 Gravestone Corrosion Collection 20
    3.4 Assessment of Research Objectives 23
        3.4.1 Tree cover 24
        3.4.2 Gravestone aspect 25
        3.4.3 Local elevation differences 26
        3.4.4 Gravestone color (algae/lichen) 26
        3.4.5 Gravestone texture 27
    3.5 Analysis of Corrosion Data 28
        3.5.1 Statistical analysis 28
        3.5.2 GIS spatial and temporal analysis 32
    3.6 Calculating Atmospheric Concentrations for Acid Deposition 33
4. Results 34
    4.1 Statistical Analysis of Variable Effects 38
        4.1.1 Tree cover 38

4.1.2 Elevation... 40

4.1.3 Gravestone color... 42

4.1.4 Gravestone texture..43

4.2 Dataset Adjustments……………......…………...44

4.3 Spatial and Temporal Assessment of Corrosion...57

5. Discussion..64

5.1 Conversion of Acid Deposition to Acid Concentration..............................70

6. Conclusion..74

References.. 76

Appendix A..82

List of Tables

Table 1 Manufacturing specialties of the Black Country....9

Table 2 Lettering alteration index.... 14

Table 3 2010 gravestone selection criteria....21

Table 4 2010 cemetery variable classification.... 24

Table 5 Cemetery locations: name, neighborhood, district, and county.... 35

Table 6 Cemetery variable p-values....38

Table 7 Collected cemetery variable information.... 47

Table 8 Cemetery break point analysis and associated cemetery corrosion rates....56

Table 9 Adjusted cemetery corrosion rates for ArcGIS ® analysis.... 59

Table 10 UK anthropogenic emission decrease from 1980-2002.... 68

Table 11 Pre- and post- environmental clean-up cemetery corrosion rates.... 69

Table 12 AURN SO_2 atmospheric concentration yearly averages....71

Table 13 JQK/JQW 2000-2010 acid deposition rates....71

List of Figures

Figure 1 Regional and county boundaries of the West Midlands.....................................7

Figure 2 Black Country coal-measures...8

Figure 3 Measurement of corrosion depth on lead-lettered inscriptions.........................22

Figure 4 Lead-lettering corrosion threshold...23

Figure 5 Cemetery variable: tree cover.. 25

Figure 6 Cemetery variable: aspect..26

Figure 7 Cemetery variable: color..27

Figure 8 Cemetery variable: texture...28

Figure 9 Example of corrosion rate and break point analysis.. 32

Figure 10 Spatial distribution of cemeteries (2010 dataset and 2005-2008 dataset)........34

Figure 11 Unadjusted cemetery corrosion measurements...37

Figure 12 JQK and JQW tree cover..39

Figure 13 Unadjusted cemetery corrosion rates: tree cover.. 40

Figure 14 Unadjusted cemetery corrosion rates: elevation.. 41

Figure 15 Tree cover and elevation statistical interaction...42

Figure 16 Unadjusted cemetery corrosion rates: color..43

Figure 17 Unadjusted cemetery corrosion rates: texture...44

Figure 18 Corrosion adjustment and non-linear model results for BIL gravestone 10....48

Figure 19 Cemetery and gravestone non-linear model results for BIL...........................49

Figure 20 Fitted corrosion rate and adjusted gravestone measurements for BIL.............50

Figure 21 Break point analyses and corrosion rates for all cemeteries........................... 51

Figure 22 Spatial and temporal distribution of adjusted cemetery corrosion rates.......... 60

Figure 23 Spatial and temporal distribution of corrosion rates (PPA, PRE)....................63

Figure 24 Historic population growth of Birmingham, 1864-1909................................ 66

Figure 25 Conversion of corrosion rates to acid deposition..70

1. Introduction

The onset of the Industrial Revolution in central England in the early 1700s changed the face of civilization. Industrial activities quickly spread throughout the area known as the Black Country, where coal seams were exposed near the surface (Court, 1946). The proximity of this resource to the surface allowed for ease of extraction, often achieved at a local level through the lower levels of houses (Black Country Living Museum, 20 June 2010). Within a relatively short period, emissions from smelters and factories fouled the air with pollution and particulates, and gave new meaning to the name Black Country (Allen, 1946). By 1850, the Midlands became the center for iron smelting and industry (Court, 1946). Air quality deteriorated rapidly from the massive amounts of industrial and residential emissions caused by local burning of high sulfur coal. Although written accounts describe the deteriorating air and environmental quality in the English Midlands (Burritt, 1868) there are no quantitative assessments of the ambient conditions.

This investigation seeks to quantify air quality over the last 160 years using lead-lettered marble gravestone corrosion as a proxy for acid deposition. Marble corrosion has been shown to be a sensitive indicator of air quality (Gauri and Holdren, 1981) and can be used to quantitatively determine minimum acid deposition rates (Dragovich, 1991; Cooke et al., 1995; Inkpen and Jackson, 2000). Because pollution and particulates from industrial emissions are linked to chronic and acute health problems (Bates, 1996), assessing the extent of air pollution and implementation of environmental legislation is necessary. Anthropogenic emissions have been linked to acidification of surface waters (Battarbee et al., 1990; Kramer et al., 1986), damage to vegetation (Allen, 1946; Johnson and McLaughlin, 1986), and corrosion of buildings and monuments (Albin, 1995; Callister, 2003; USGS, 1999). Although sulfur dioxide (SO_2) and nitrogen oxides (NO_x) also occur naturally, industrial and residential burning of fossil fuels are major contributors to anthropogenic emissions (Gauri and Holdren, 1981; Metcalfe and Whyatt, 1995). The United Kingdom decreased SO_2 emissions by 79 percent and NO_x emissions by 39 percent from 1980 to 2002 (Klein et al., 2004). These two atmospheric pollutants can rain out as either dry deposition near the source or wet deposition after the precipitation becomes oxidized and is carried a significant distance before it falls (Gauri and Holdren, 1981; Metcalfe and Whyatt, 1995). Increasing usage of fossil fuels, as a result of industrial and residential growth, plays a dominant role in the formation of corrosive gas and acid rain (Tecker, 1999). Consequently, expected increases in SO_2 emissions from industrial and/or residential expansion would increase the dissolution of carbonate monuments (Meierding, 1993b).

Conversion of marble monument corrosion to atmospheric deposition rates provides a spatial and temporal record of the distribution of acid deposition from industrial and residential expansion and can serve as a quantitative measure of acid rain and therefore acid deposition rates. Previous studies indicate monument corrosion is a robust measure of acid deposition and may provide insights into the sources of acid precipitation (Cooke, 1989; Cooke et al., 1995; Inkpen, 1998). For example, data suggest the relative contribution of industrial verses residential sources of SO_2 pollutants can be deciphered spatially (H. D. Mooers, personal communication, 2010). The proximity of the industrial and/or residential centers to peaks in gravestone corrosion data provides a spatial map to address relative contributions of these centers.

The 2005-2008 dataset (Putz et al., 2005; Mooers et al., 2006; H. D. Mooers, unpublished data) contains 550 gravestone inscription measurements from 260 stones across the West Midlands collected between 2005 and 2008. These data were limited primarily to corrosion measurements. No consideration was made to assess differences in stone, physical setting, or environmental variables.

During 2010, 848 inscriptions were measured on 329 gravestones from 14 cemeteries (five overlapping with 2005-2008 dataset cemetery locations). Detailed descriptions of individual gravestone conditions were collected to assess stone and cemetery variability. Variables likely to impact corrosion on marble gravestones include tree cover, gravestone color (algae/lichen cover), gravestone aspect (facing orientation), gravestone texture, and local elevation differences. This manuscript seeks to quantify acid deposition as a result of the industrialization and urbanization of the industrial centers of the West Midlands. More specifically, it seeks to estimate the relative contributions of residential and industrial pollution signals. Including the 2010 study, a total of 1,398 gravestone inscriptions were measured on 589 stones in 33 cemeteries.

The 2010 data were analyzed statistically to examine the effects of tree cover, gravestone color (algae/lichen cover), aspect, gravestone texture, and local elevation differences on gravestone corrosion. Based on the statistical analysis, corrosion data were adjusted for stone type, physical setting, and environmental conditions. 2005-2008 data was not adjusted unless variable information was recorded. These adjusted data were then combined with the 2005-2008 dataset to produce spatial and temporal maps of cemetery corrosion rates throughout the West Midlands.

Results indicate that monument corrosion varies widely across the study area with the highest corrosion rates correlating to major industrial and/or residential centers. Statistical analysis indicates that monument corrosion is correlated with all variables (tree cover, gravestone texture, local elevation differences, and gravestone color (algae/lichen cover)) and is statistically significant with p-values ≤ 0.5.

2. Background

2.1 Industrialization History of the West Midlands

For the purpose of this discussion an industrial center is defined as a county or district active in the mining and/or manufacturing of goods. Conversely, a residential center is a densely populated area where burning of fossil fuels is limited to domestic usage and the manufacturing of goods is limited to local skilled craftsmen. A residential center is different from an urban area because of its sparse population and agricultural dependence. There has been some discrepancy and limitation of information in the causes of localized industrialization (Allen, 1966) and the spatial and temporal development of the West Midlands (Lee, 1986). Every reasonable attempt has been made to accurately and thoroughly describe these events as they have occurred, but lack of available information or agreement may have resulted in regional generalizations of industrial history.

The spatial and temporal distribution of acid rain is a direct result of the changing patterns of industrialization of the West Midlands. The physical setting of central England played an important role in the onset of industrial activities (Figure 1). Even during Medieval times the Black Country was an industrial center (Allen, 1966). Natural resources such as coal, sandstone, and limestone were abundant, prolific aquifers were available, and a network of canals provided transportation (Allen, 1966).

The Black Country is an area of the West Midlands (Figure 2) occupying portions of [the historic boundaries of] south Staffordshire and northwest Warwickshire (Allen, 1966). The area first became known as the Black Country because of the underlying coal measures outcropping at the surface (Allen, 1966; Court, 1946). These coal measures include 13-14 seams of coal of which converge in the area. The coal-measures are overlain by Permian and Triassic strata which were subsequently folded into an anticline structure (Allen, 1966). The anticline structure and folded strata allowed for surface mining of coal and ironstone as it was exposed at the surface (Black Country Living Museum, 20 June 2010). The presence of these rocks became important in the locality of industrial centers. The industrial expansion of south Staffordshire [West Midlands County] was not concentrated in a single town or particular district (Allen, 1966). Rather the industrial expansion occurred where coal, ironstone, and water were easily accessible. The industrial revolution is generally considered to have begun in Ironbridge in rural Shropshire (Simmons, 2005). However, industrial centers sprang up nearly simultaneously throughout the region. Local manufacturing processes of the Midlands ranged from specialties in ironmongery to flint glass (Court, 1946). Table 1 lists many of the early industrial centers and the major groups of goods produced.

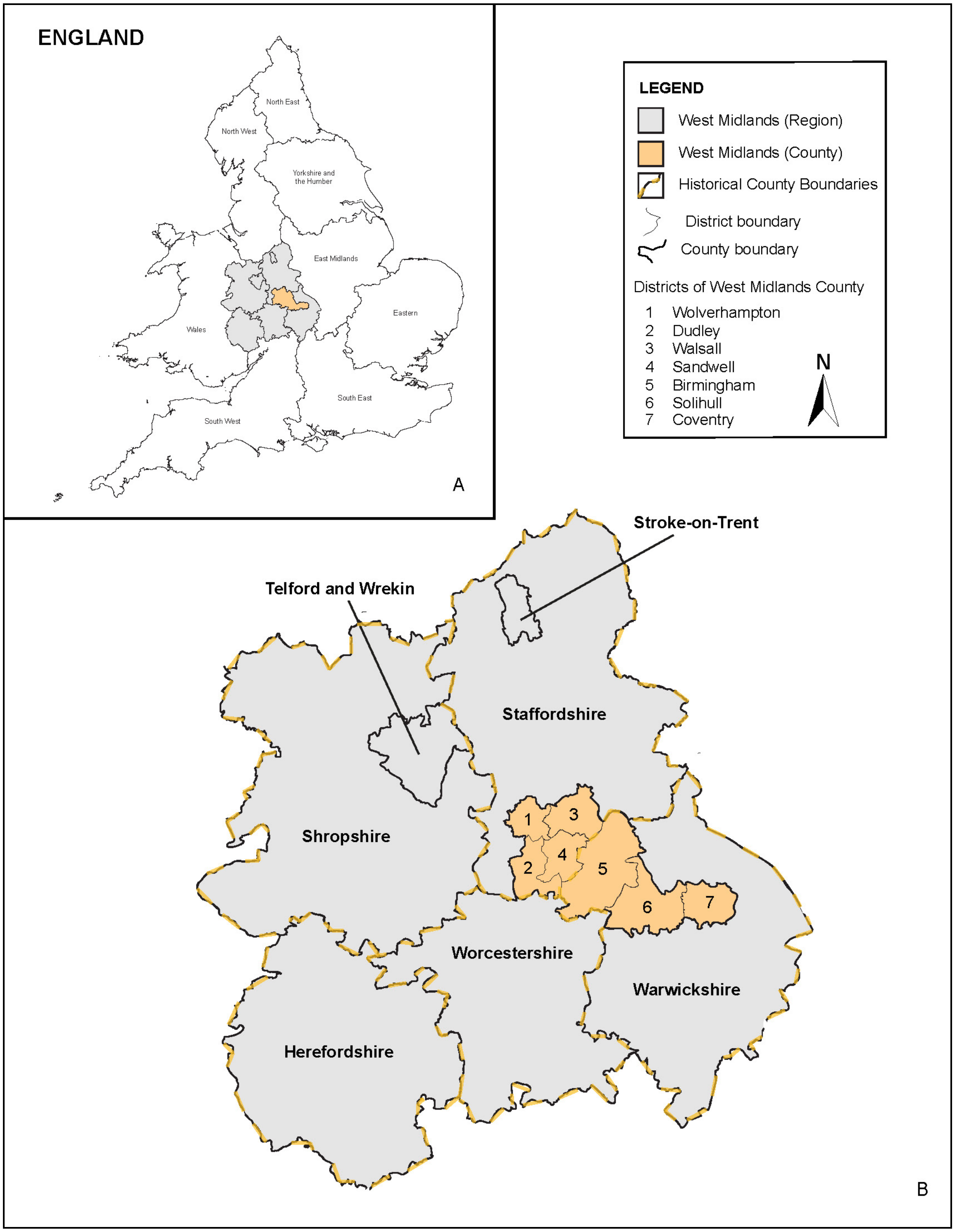

Figure 1. (A) Regional boundaries of England. (B) Current county boundaries of the West Midlands region. Historically, the West Midlands County did not exist; rather it existed as parts of south Stafforshire, and northwest Warwickshire. Historical boundaries were interpreted from old geographic maps (Phillips Handy Atlas, 1892a-b). Modified from the Office for National Statistics Geography GIS and Mapping Unit (2009a-b).

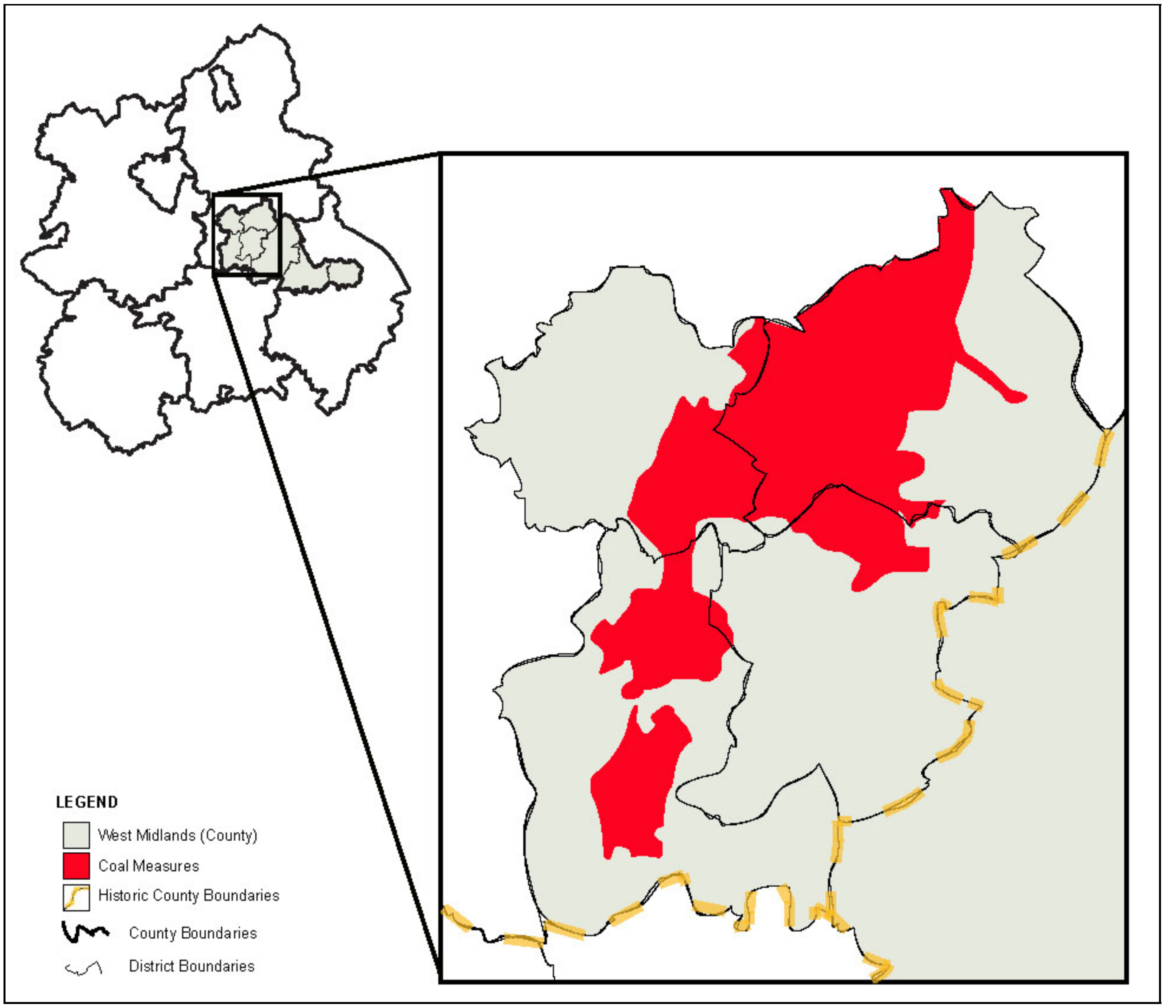

Figure 2. The coal-measures primarily occupied the West Midlands County and were focused to portions of the Wolverhampton, Walsall, Sandwell, and Dudley districts. Modified from the Black Country Geological Society (2006) and Office for National Statistics Geography GIS and Mapping Unit (2009a-b).

Table 1. Manufacturing specialties of the Black Country industrial centers (Black Country Living Museum, 20 June 2010).

Cities of the Black Country	Manufacturing Specialties
Bilston	Specialized in iron and enamelling trade.
Bloxwich	Mining of the local raw materials is responsible for the development of this village into an industrial town. In 1865, Bloxwich specialized in awl-blade manufacture with 45 skilled craftsmen. Bloxwich was the first to produce stainless steel tableware in the 1930s.
Brownhills	By the1750s coal-measures at the surface had diminished forcing underground extraction of the raw materials.
Cannock Coalfield	Coal was mined from 1700 to the 1960s. Local coal extraction declined in production by the 1860s.
Darlaston	A 30 foot coal-seam outcropped in parts of Darlaston making it accessible to be mined at the surface and from the basements of houses. Gun making was a local trade of Darlaston. Eight large factories and many smaller operations were present in 1860.
Sandwell	Known for coal, iron, mining, quarrying, and ironfounding. Canals provided transport of these raw materials until the 1970s.
Smethwick	Specialized in glass working. Land was populated with farms and cottages when manufacturing arrived. Population increased by 50,000 by the twentieth century.
Tipton	In 1719, the first steam engine was used to pump water from coal mines.
Walsall	Specialized in bits, stirrups, and spurs as independent trades in the early seventeenth century.
Wednesbury	As the demand for gun barrels and gun locks slowed by 1815 production focused on making tubes.
West Bromwich	The area did not develop until the discovery of coal and ironstone in the region. In 1590, West Bromwich has the first blast furnace in the Black Country. Specialized in spring manufacturing, holloware, and architectural cast ironware.

Shaft mining of surface materials began in the seventeenth century resulting in 100,000 tons of extracted coal and ironstone by 1710 (Black Country Living Museum, 20 June 2010). By the mid-nineteenth century, production of coal and ironstone grew exponentially to one million tons of raw material and peaked in 1860 with eight million tons. In the 1880s, the basic industries of the Black Country were of iron, coal, and textiles (Table 1) (Hey, 1972). Coal and iron-making were the common businesses at a residential level though to a lesser degree than in major industrial centers (Burritt, 1868). During the height of the industrial expansion the city of Dudley was described as being lifted above the smoke of the Black Country and yet engulfed in its own envelope of smoke from local furnaces (Burritt, 1868). Rural communities had 'dual-occupations' where farmers would tend to their agricultural lands but also partake in local metal workings. 'Dual-occupations' were attractive because they provided workers with an escape from the grueling conditions of the metal working lifestyle. It was no longer profitable to manufacture a limited number of metalware goods on a part-time basis as machinery entered the scene by the mid-nineteenth century (Hey, 1972). As the industrial centers grew, changed emphasis, and coalesced into larger cities, so did the residential centers that supported those industries. Elihu Burritt, the American Consul in Birmingham, described the ambiance of the Black Country as follows: “And all the while, the furnaces roar and glow by night and day, and the great steam hammers thunder, and hammers from an ounce in weight to a ton, and every kind of machinery invented by man, are ringing, clicking, and whizzing as if tasked to intercept all this raw material of the mines and impress upon it all the labour and skills which human hands could give to it” (Burritt, 1868).

These changing patterns of industrialization were based on resource availability, labor availability, as well as the influence of historical events such as wars. The peaks in the industrialization of the region were bolstered by the demands of war (Allen, 1966). It was a time period of net movement towards the city centers because mechanization of agriculture meant that fewer people were needed to produce the food in the country. The industrial centers engulfed the surrounding residential areas as demands for products increased. Historical events such as World War I (WWI) and World War II (WWII) changed the needs of the industrial centers. As demand for goods grew, industrial centers grew and coalesced into larger city centers. In the early twentieth century, numerous small industrial centers throughout the English Midlands began to move into fewer, larger industrial centers, culminating in the years following WWI with Birmingham as one of the main industrial complexes.

The compact nature of the Black Country made transportation of fuels and raw materials easy through the use of canals (Allen, 1966). The successful development of the city of Birmingham as a major industrial center owes a great deal to these economic resources of the Black Country (Burritt, 1868). The location of the Birmingham industrial center on the outskirts of the Black Country was marked by an excellent water source, locality to raw materials and fuel, and also a large specialized labor-force (Allen, 1966). In the latter part of the eighteenth century a canal was built to link the Birmingham city center to Wolverhampton (Allen, 1966). Birmingham used a series of canals to transport fuel and raw materials, from the Black Country, necessary for the manufacturing of highly finished products to the industrial centers of the city. It was the Permian sandstone strata on which the city of Birmingham sits that provided an excellent source of water suitable to support this sophisticated industry and large population (Allen, 1966).

The Black Country was unable to spare additional labor to accommodate the increasing demand for the highly finished products the Birmingham industrial centers later became known for. The industrial expansion in Birmingham did not happen as one rapid transformation from small-scale industry to large-scale industry; rather it was a gradual progression of the eighteenth century industry (Allen, 1966). The specialized industries of Birmingham included brass goods, guns, buttons, and jewelry (Allen, 1966). The poor soils within the city of Birmingham could not sustain agriculture; instead workers relied upon their specialized craftsmanship (Hey, 1972).

2.2 Acid Precipitation Associated with Industrialization

Unpolluted, natural precipitation has a pH of 5.6 due to equilibration with atmospheric carbon dioxide (CO_2) (Bubenick, 1984). Acid rain is created though reactions with NO_x and SO_2 that form precipitation with a pH less than 5.6 (Gauri and Holdren, 1981). CO_2 reacts reversibly with water to form carbonic acid (H_2CO_3) in the atmosphere (Equation 1). Even in the absence of any industrial contaminate natural precipitation will gradually corrode carbonate (and silicate) rocks because of its slight acidity. NO_2 produced from industrial and automotive sources reacts to form nitric acid (HNO_3) and nitrous acid (HNO_2) (Equation 2). Similarly, SO_2 forms from the burning of coal and reacts with water in the atmosphere to produce sulfurous acid (H_2SO_3) and/or sulfuric acid (H_2SO_4) (Equation 3). The atmospheric chemical reaction equations of these gases are as follows:

1. $$2\ H_2O_{(l)} + CO_{2(g)} \leftrightarrow H_2CO_3 + H_2O \leftrightarrow H_3O^+_{(aq)} + HCO_3^-{}_{(aq)}$$
2. $$2\ NO_{2(g)} + H_2O_{(l)} \rightarrow HNO_{3(aq)} + HNO_{2(aq)}$$
3. $$SO_{2(g)} + H_2O_{(l)} \rightarrow H_2SO_{3(aq)}$$
   $$2\ SO_{2(g)} + O_{2(g)} \rightarrow 2\ SO_{3(g)}$$
   $$SO_{3(g)} + H_2O_{(l)} \rightarrow H_2SO_{4(aq)}$$

Deposition of acid, with a focus on sulfur oxides, can be recorded through corrosion of calcium carbonate ($CaCO_3$) stones and monuments. $CaCO_3$ stones include limestone and marble (metamorphosed limestone). Monument corrosion data can then be converted to acid deposition rates. Because we are concerned with high sulfur coals, SO_2 emissions were assumed to be primary. SO_2 reacts with $CaCO_3$ by the following reactions:

Acid rain reacts with calcium carbonate:

$CaCO_{3(s)}$ + acid rain $\rightarrow$ $Ca(HCO_3)_{2(aq)}$

Therefore one mole of sulfur dissolves one mole of $CaCO_3$ by the reaction:

$H_2SO_{4(aq)} + CaCO_{3(s)} \rightarrow CO_{2(g)} + CaSO_{4(aq)} + H_2O_{(l)}$

Total mass of acid deposition of SO_2 can then be determined from corrosion measurements, assuming corrosion is due primarily to sulfuric acid (from burning high sulfur coal).

2.3 Carbonate Corrosion Measurement Techniques

The complex history of industrial and residential development in central England during the Industrial Revolution led to an equally complex history of the spatial and temporal distribution of acid rain. Much of the work on the history of acid rain has been completed by Robert Inkpen and colleagues (e.g. Inkpen, 1998; Inkpen and Jackson, 2000; Inkpen et al., 2000; Inkpen et al., 2001) using monument corrosion as a proxy for acid deposition. These studies use a variety of techniques for analyzing the corrosion of lettering on monuments and monument surfaces. The techniques involve assessment of lettering depth, width, and sharpness by either qualitative assessment or quantitative measure. Rahn (1971) and Meierding (1993a) describe the lettering alteration index, which qualitatively categorizes the inscription lettering legibility as a result of acid deposition (Table 2). Others use quantitative stone measurements by taking high resolution close-range images (close-range photogrammetric analysis) (Inkpen et al., 2000) or measurement of stone slab thickness (Mierding, 1993b). When available the use of lead-lettered marble stones provides the most accuracy in determining acid deposition rates (e.g. Cooke et al., 1995; Dragovich, 1991; Inkpen and Jackson, 2000).

Close-range photogrammetric analysis described by Inkpen et al. (2000) is a non-destructive method of assessing surface stone loss to acid deposition. This method uses a specialized camera with a fixed focal length and photogrammetric station. Accuracy is controlled by the quality of the photograph from which scaling and orientation data can be extracted to model the stereoscopic surface. Photogrammetric analysis along with Geographical Informational System (GIS) is used to create a map of building corrosion, allowing for a spatial comparison of data (Inkpen et al., 2000; Inkpen et al., 2001). This method should always be subject to field verification because photos can have a false sense of depth from factors such as shadows (Inkpen et al., 2000).

Table 2. Lettering alteration index. Assessment of the legibility of carved gravestone inscriptions. Modified from Rahn (1971).

Class	Indicators of Class
1	Lettering has distinct, sharp edges. No evidence of corrosion is evident.
2	Letter edges are slightly rounded showing some evidence of corrosion and stone loss.
3	Letter rounding is more apparent. Edges may completely be removed but lettering remains legible.
4	Lettering has become further rounded. Most, if not all, edges have been removed. Lettering remains legible.
5	Letters are disintegrating. Most letters are legible but is becoming indistinguishable.
6	Lettering has virtually disappeared.

Typically the lead-lettering technique is applied to marble gravestones or monuments. Marble is ideally suited for inscribing with flush lead-lettering technique. Flush lead-lettering is accomplished by first carving recessed lettering into the gravestone. Several holes are then drilled into the base of each carved letter, and pre-formed lead letters are hammered into the recessed lettering. A sharp chisel is used to trim off excess lead making it flush with the stone. Marble is composed almost exclusively of the mineral calcite which is particularly susceptible to dissolution by acid. As the stone weathers, the letters remain and become raised above the surface of the stone. The amount of corrosion can be measured with a depth micrometer or digital depth probe.

2.4 Assessment of Marble Monument Corrosion

Although modelers have played an important role in the development of environmental policies (Metcalfe and Derwent, 1989), using marble gravestone corrosion provides a physical measure of the minimum amount of acid deposition necessary for marble dissolution. Comparison of both model outputs and measurement of acid deposition at monitoring sites (Metcalfe and Derwent, 1989) provided validation of atmospheric acidification.

Gravestone studies conducted by Cooke et al. (1995) used the lead-lettering index and lettering depth as a measurement of acid deposition and assumed lead-lettered inscriptions were chiseled and polished flush with the marble surface. Corrosion was assumed to be zero when the lead-lettered inscription was chiseled and polished flush.

The lead-lettering method of measurement may be quite accurate for measuring the effects acid deposition exposure within a few years. This method is not suitable for gravestones on the order of a century old because letters can weather out of the stone entirely, especially in highly polluted regions.

Studies were limited to gravestones without heavy ornamentation because such ornamentation may influence the distribution of acid deposition across the gravestone surface (Cooke et al., 1995; Inkpen and Jackson, 2000). Cooke et al. (1995) also limited inscription measurements to vertical standing gravestones with planar, rectangular surfaces. Local environmental weathering rates may also be influenced by tree cover, buildings, and other overhanging structures. Gravestone aspect (facing orientation) varies across the study region, West Midlands, UK, and may also contribute to the pattern of acid deposition detected on the stone surface. Therefore measurements should be constrained to gravestones with a designated aspect. Inkpen and Jackson (2000) suggest monument material, weathering environmental conditions, and processes of weathering regionally vary both spatially and temporally. Several studies limit measurement of depth of corrosion to the following letters on the gravestone inscription: 1, A, E, and O (e.g. Cooke et al., 1995; Inkpen and Jackson, 2000). Considerations for measurements were made for the following influences to limit additional variability: locations of measurements on gravestone, geometry of gravestones used in study, effects of tree coverage and aspect (Cooke et al., 1995). Due to capillary movement of groundwater, the lower part of the gravestone may be subject to prolonged exposure to acidic water;

therefore measurements were taken from the upper most part of the gravestones (Cooke et al., 1995).

Contributions of industrial and residential coal burning to acid deposition have been another focus among corrosion studies. Cooke et al. (1995) measured the amount of corrosion on gravestones from three urban regions to determine the effects of population size and industry. The more industrialized region, as expected, resulted in a higher corrosion rate than the two less industrial centers.

Mooers (unpublished data) focused on the pollution history of the West Midlands. The results of the 2005-2008 data (H. D. Mooers, unpublished data) suggested the contribution of residential emissions to be more influential than industrial emissions. Likely, the pattern of acid deposition is dependent on the relative location of emission release; industries emit SO_2 and NO_x higher in the air column from smoke stacks, whereas residential sites emit pollutants via chimneys allowing for concentration of pollutants at ground level. Domestic chimneys have historically played a rather crucial role in air quality degradation as have industrial smoke stacks (Brimblecombe, 1987). In the early nineteenth century smoke abatement legislation (Albin, 1995) was proposed to reduce the smoke emissions from industrial factories and residential houses (Brimblecombe, 1987). However, it was difficult to enforce a limitation on domestic emissions, thus the legislation aimed to control primarily contributions of the industrial factories. The legislation did raise awareness with the public so that they began to take ownership and responsibility with their domestic smoke (Brimblecombe, 1987).

Mooers (unpublished data) found corrosion rates in the Birmingham city center were fairly constant from 1860 to 1975 when implementation of pollution control measures dramatically reduced acid deposition rates. The outskirts of residential regions recorded little corrosion until after World War I when urban populations grew rapidly. By using marble gravestone corrosion as a proxy for environmental degradation, the assessment of the effects of industrialization and urbanization necessary for the implementation of environmental pollution control measures was possible. There was a marked decrease in the rate of monument corrosion between about 1968 and 1975 resulting from environmental cleanup following the establishment of environmental regulations in the 1970s (H. D. Mooers, unpublished data). Mooers (unpublished data) also suggests a difference between a residential and an industrial contaminate source identifiable within the gravestone corrosion data. There are, however, several artifacts in the data yet unexplained: 1) although corrosion measurements on a single gravestone inscription are consistent, there is considerable unexplained variability among gravestones within a single cemetery (corrosion on adjacent stones can vary by a factor of two or more); and 2) the contribution of industrial vs. residential sources of pollution has not been addressed.

3. Methods

3.1 Spatial Distribution of Cemetery Selection

Cemeteries for the 2010 study were chosen to satisfy voids in the 2005-2008 dataset's (H. D. Mooers, unpublished data) spatial distribution of cemetery coverage. Mooers (unpublished data) focused on spatial and temporal history of acid deposition in the West Midlands, with an emphasis on the Birmingham city center and adjacent regions of Warwickshire, Staffordshire, and Worcestershire. The combination of the cemetery gravestone corrosion measurements of the 2005-2008 and 2010 datasets allows for a thorough assessment of the spatial and temporal distribution of acid deposition in the West Midlands.

3.2 Marble Gravestone Selection

Marble became a popular choice for gravestone markers in England, mainland Europe, North America, and Australia by the mid-nineteenth century. In England, most of the marble used was likely imported from Carrara, Tuscany, Italy (Tony Sames, personal communication, June 2010). Although information regarding the origin of the marble gravestones was limited, cemetery keepers in the study area referred to the gravestone type as Carrara marble. However, there are no sources to validate the province of origin of marble for these gravestones. Carrara marbles are comprised almost entirely of pure calcite within a primarily homogenous fabric (Molli et al., 2000); thus, Carrara marbles are well-suited for building materials and monuments. Investigations were conducted on marble gravestones which had been inscribed with the flush lead-lettering technique.

3.3 Gravestone Corrosion Collection

To maintain consistency with Mooers (unpublished data), gravestone selection was focused to criteria listed in Table 3. Corrosion measurements for this study were gathered using a digital caliper with ± 0.02mm instrument error (Sealey Professional Tools). The depth probe on the digital caliper was used to measure the depth of receded marble from the lead-lettering surface (Figure 3). Resting the digital caliper on two neighboring lead letters provided more stability in measurements while reducing the error in skewed depth reading from tilting of the digital depth probe. In the study area, it was common for gravestones to contain multiple inscriptions per stone; often two and as many as five inscriptions on a single gravestone. Inscriptions were chronologically inscribed on the gravestone with the oldest on top and the youngest at ground level. For each inscription added to a gravestone, the marble was resurfaced below the existing inscriptions. Resurfacing the marble provided a 'clean slate', so to speak, for the new inscription to be placed. After inserting lead into the engraved lettering, the entire inscription was polished flush thus setting the inscription to a net zero corrosion at the time of inscribing. Assuming the inscription was inscribed within a year of the individual's death, the depth measurements gathered on the inscription provide an average depth of corrosion for the elapsed time since death. On each inscription, ten measurements were gathered along the date line, and the high and low values were thrown out. The remaining eight values were averaged. The trimmed mean was used because it is less sensitive than an overall average to the minimum and maximum values.

Table 3. 2010 gravestone selection criteria. Not all selection criteria were rigorously followed in the 2005-2008 dataset (H. D. Mooers, unpublished data). If identifiable discrepancies were present, data was excluded from the statistical analysis.

Gravestone Selection Criteria	Exceptions	Description
Marble	0	For consistency, all corrosion measurements were collected on marble gravestones.
Vertical standing	0	No horizontal gravestones were measured in this study to maintain consistency with 2005-2008 data (H. D. Mooers, unpublished data).
Planar-surfaced	1	One book style gravestone was used for the collection of corrosion measurements. Measurements were gathered in such a way that the curvature of the gravestone did not affect the way the caliper rested on the neighboring letters.
Lead-lettering	0	Lead or plastic-like composite materials were sampled for measurement. If lead-lettered gravestones were not available then the plastic-like composite inscriptions were used. Both the lead and plastic-like composite were resistant to acid precipitation.
≥ Two inscriptions per stone	1	If gravestones fitting this selection criteria were lacking or if stones were not otherwise available to address variables, only then, were gravestones with fewer than two inscriptions used for corrosion measurements.
Chronological inscriptions	1	If inscriptions on the stone were out of order, the year represented on the date line may misrepresent the amount of acid precipitation corroding the stone over that time period.
Limited ornamentation	0	No stones with heavy ornamentation were included because it may shelter the stone from acid precipitation. Gravestones with heavy ornamentation of varying relief, such as carvings and/or ledges predominately located at the top or sides, were excluded from data collection.
Evidence of resurfacing	0	Evidence included visual identification (color differences between inscriptions), textural differences, and depth readings on inscription lettering.

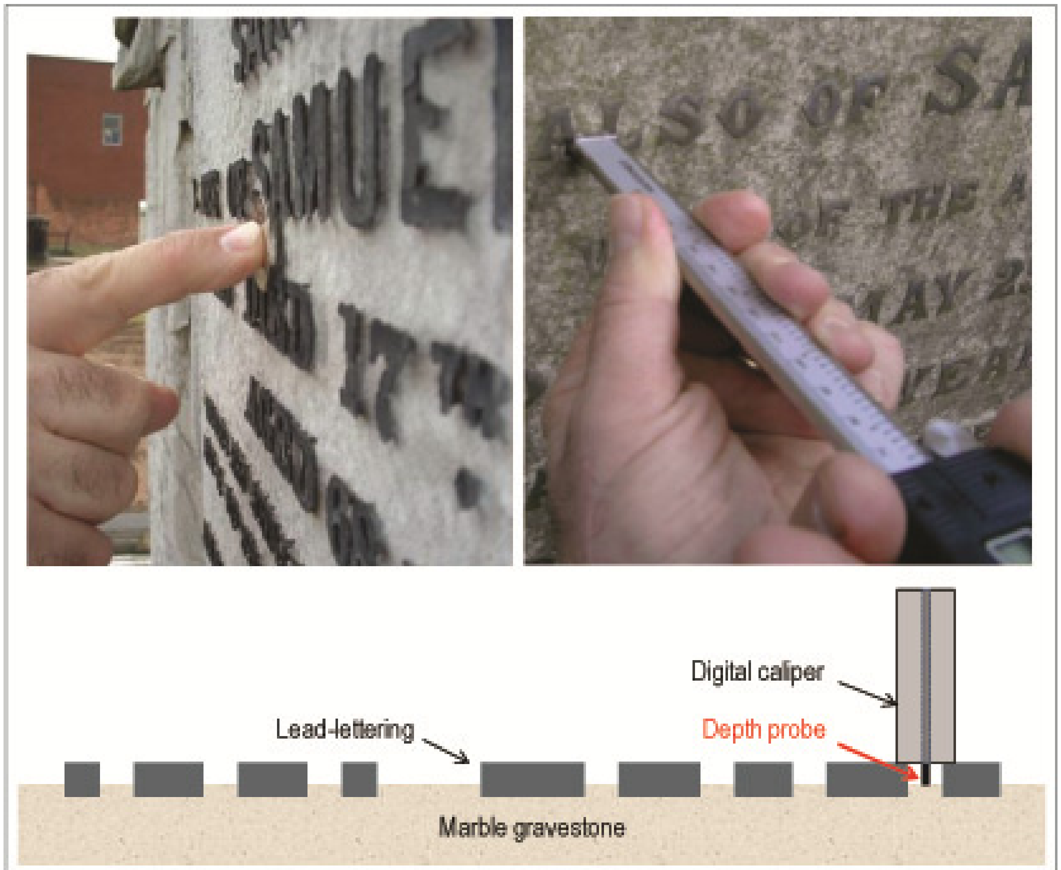

Figure 3. The marble recedes as a result of acid deposition on the gravestone surface, leaving the lead-letters raised from the marble surface. Depth measurements were gathered between two lead-letters by the depth probe on the digital caliper. The schematic illustrates a profile view of the lead-letters, marble surface, and placement of the digital caliper.

The threshold at which corrosion measurements can be collected is defined by the length of time the letters maintain in their initial embedded placement. This threshold exists, as lead-lettering will eventually fall out of the marble surface (Figure 4). Measurements gathered in the 2010 and 2005-2008 studies represent minimum corrosion measurements for two reasons: 1) the marble surface recedes as a result of excessive corrosion; and 2) the measurements record only the amount of acidified water that has reacted with the marble gravestone and not the runoff water.

Figure 4. How resistant the marble is to corrosion is a function of the degree of metamorphism and recrystallization. 'Soft' marbles are more susceptible to acid deposition and as a result will corrode more quickly than 'hard' marble gravestones. Corrosion rates are influenced by porosity, crystal size, joints and fractures as a result of metamorphism and recrystallization, and mineralogical variability.

3.4 Assessment of Research Objectives

The 2005-2008 gravestone corrosion dataset (H. D. Mooers, unpublished data) shows considerable variability in corrosion measurements within cemeteries. Variability is a function of the inherent properties of the stone and the physical setting. Cemetery variables assessed in this study are tree cover, aspect (orientation or facing direction), local elevation differences within a single cemetery, gravestone surface texture, and gravestone color (algae/lichen) (Table 4). However, there are additional sources of variability in the susceptibility of gravestones to corrosion, including factors such as internal physical properties of the marble stone (i.e. crystal size, orientation of crystals, porosity). Because marble stone samples could not be collected from gravestones, such variability could not be addressed in this study.

Table 4. 2010 cemetery variable classification.

Cemetery variable	Classification scheme for cemetery variables
Tree	Y = Presence of tree cover N = No tree cover
Texture	R = Rough, bumpy marble surface S = Smooth polished marble surface
Color	W = White marble, no surface covering of algae/lichen F = Light covering of algae/lichen, light grey in appearance M = Moderate covering of algae/lichen, grey in appearance D = Heavy algae/lichen cover, dark grey in appearance
Elevation	H = Local topographic highs within a single cemetery L = Local topographic lows within a single cemetery

3.4.1 Tree cover

The effects of tree cover on corrosion measurements were addressed by sampling gravestones both under direct tree cover and not under tree cover (Figure 5). Approximate ages of trees were assessed from truck girth measurements and species information; assuming a one inch diameter increase per year. Trees approximately 80 to 100 years old were targeted for this study. It was important that trees be old enough to have provided shelter to the underlying gravestones during heavy industrial and/or residential development. Gravestones lying directly beneath the tree canopy were noted to be under tree cover. The assessment of this variable was conducted by collecting measurements from gravestones directly under the tree canopy. Gravestones under the outer fringes of the tree canopy were not collected for assessment of this variable.

Figure 5. Gravestones in the foreground of this picture were characterized as not under tree cover. Gravestones located in the background of the picture were marked as under tree cover. If an open area within the cemetery looked suspiciously like it may have had tree cover, gravestones were avoided for measurement. Mature, well-established tree cover was targeted for characterization of this gravestone variable.

3.4.2 Gravestone aspect

Gathering depth measurements from gravestones with varying aspects would provide additional information on the effects of, for example, wind direction. However, because most cemeteries restrict burial plots to two opposing directions (e.g. aspects of 90 and 270 degrees) finding multiple cemeteries with varying aspects proved challenging. Bilston Cemetery (BIL) was a unique exception in this study. The circular drive (Figure 6) enabled collection of corrosion measurements for varying aspects.

Figure 6. Gravestone selection for BIL cemetery, to assess the effects of aspect, were focused to gravestones lying on the inside and outside of the dashed yellow line.

3.4.3 Local elevation differences

Local elevation differences within a single cemetery were defined as relative topographic highs and relative topographic lows (Table 4). Only three cemeteries visited for the 2010 dataset and 2005-2008 dataset had significant local elevation differences within the cemeteries, tens of meters difference.

3.4.4 Gravestone color (algae/lichen cover)

Determining the effects of gravestone color (algae/lichen cover) could aid in answering questions of how the presence of algae/lichen changes the marble surface or whether the presence of algae/lichen is pure reflection of the corrosion rate. This study focuses to identify gravestone color qualitatively in four categories (Table 4; Figure 7).

Figure 7. Classification for gravestone color. (A) White: no algae/lichen cover, (B) Fair: light covering of algae/lichen, (C) Moderate: moderate algae/lichen/moss cover, (D) Dark: algae/lichen cover is extensive and stone is quite dark.

3.4.5 Gravestone texture

It was noted by Mooers (unpublished data) that many gravestones, perhaps 10-15 percent, had rough surface textures. The uneven weathering is a result of the chemical and physical variability within marble. As a marble gravestone corrodes, recrystallized fractures or other stone impurities become raised irregularities from the surrounding marble surface. Most gravestones assessed in the 2010 study contained varying amounts of recrystallized fractures. Recrystallized fractures in marble are more resistant to corrosion than the surrounding stone resulting in a raised ridge. Gravestone texture was thus recorded as either a smooth surface, with little to no irregular bumps, or rough surface with multiple raised features (Table 4; Figure 8).

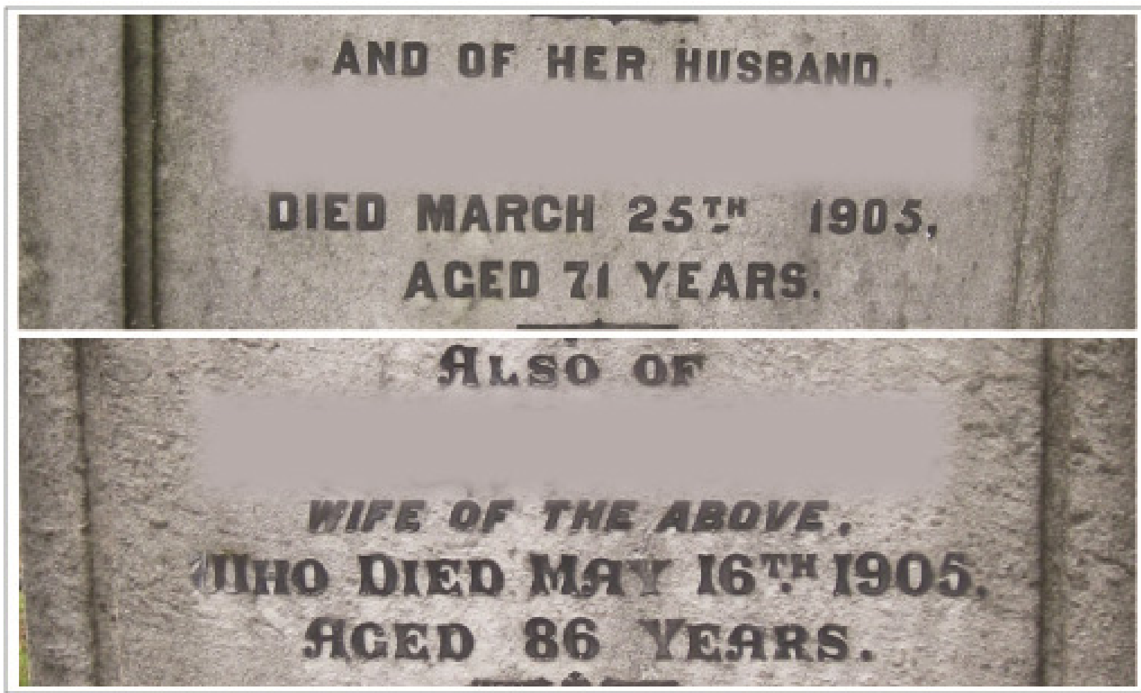

Figure 8. Gravestones with the same inscription date line represent drastically different textures. The top image is a common example of smooth texture while the bottom is an example of rough texture.

3.5 Analysis of Corrosion Data

3.5.1 Statistical analysis

Data collected during the June 2010 field season were used for the statistical analysis of cemetery variables. Relationships among cemetery variables and corrosion measurements were first evaluated by plotting and visually examining the data using Microsoft Excel. BIL was the only cemetery with a full range of aspects because of its circular layout. There was not an indication that aspect effected corrosion rates at BIL, therefore, work focused on addressing the remaining variables. Assessing the effects of aspect is also complicated by regional and local factors such as wind direction (Matejko et al., 2009). Therefore no further work on aspect was pursued. The remaining variables (tree cover, gravestone texture, gravestone color, and elevation) appeared to be correlated to monument corrosion.

To rigorously evaluate the effects of cemetery variables on corrosion measurements, statistical analysis was conducted with SAS (Statistical Analysis Software). Cemetery name, location, corrosion measurements, and variables were imported into SAS and merged into an integrated database. Once merged, data were plotted and checked for missing information. The contribution of tree cover, gravestone texture, gravestone color, and elevation were assessed using the 2010 dataset. As an initial assessment of gross errors including data entry mistakes, corrosion measurements were plotted for individual gravestones within each cemetery as a function of time. For all inscriptions within the 2010 dataset and the 2005-2008 dataset (H. D. Mooers, unpublished data), a zero mm corrosion measurement was inserted for 2010. This inserted point provides a common temporal reference frame for all data. Evaluation of recent corrosion rates on all of the 2010 data shows corrosion measurements from 2005 to 2010 to be less than the measurement error of the digital caliper (Sealey Professional

Tools). Therefore, no corrections for the five year difference in corrosion measurements were applied to the 2005-2008 data.

The effects of these categorical variables (tree cover, gravestone texture, gravestone color, and elevation) and corrosion measurements were assessed with ANOVA (analysis of variance) models. All cemetery variables were included in a single model. The models used were ANOVA models with categorical variables using the General Linear Models (GLM) and Mixed Models (MIXED). The models used the log of corrosion as a dependent variable, because multiplicative models made more sense for these data. For example, gravestone inscriptions with texture = 'R' resulted in ten percent faster corrosion than corrosion with gravestone inscriptions with texture = 'S'. The presence of tree cover resulted in an eight percent decrease in corrosion rate. It would not make sense to add or subtract an overall effect from a gravestone with very low corrosion rates because the rate could end up negative. For gravestones where tree cover was unknown, the adjustment used an overall weighted average of tree cover (Y and N) which was weighted by the percents of gravestones with known tree cover (Y and N). This assumes that the fraction of tree covered gravestones is similar in cemeteries where tree cover was not recorded to cemeteries where tree cover was recorded.

Results of the ANOVA model allow corrosion measurements to be adjusted for certain statistically significant variables and/or interactions present. These selected variables would be chosen to adjust the corrosion measurements. After the adjustment, the effect of the selected variables would then be factored out of the data. The only remaining variability in the data then reflects variables uncollected in this study.

Cemeteries were treated as random effects where there is random variability from cemetery to cemetery due in part to variability from location to location. By including the random effects in the models, gravestone corrosion measurements within the same cemetery are treated as dependent observations of the effects of the variables. The goal is to assess the general trend of the effects of cemetery variables on corrosion throughout all cemeteries.

Corrosion measurements were adjusted using the fitted effects of tree cover and gravestone texture. A discussion of why these variables were chosen for adjustment and how the adjustment was conducted will follow in the results sections. These adjusted data were then modeled in a non-linear regression model to determine break points and corrosion rates (Figure 9). SAS searches interactively to find the best fit for the break points based from the initially entered parameter values. In some cases if the initial values were not close enough to the best values, the iteration scheme may not have converged or converged to suboptimal parameter values. Plotting the final fitted values and the observed data provided a check whether the program converged to reasonable parameter estimates. Because the model is being fit over one time domain, visual assessment of the fit works well.

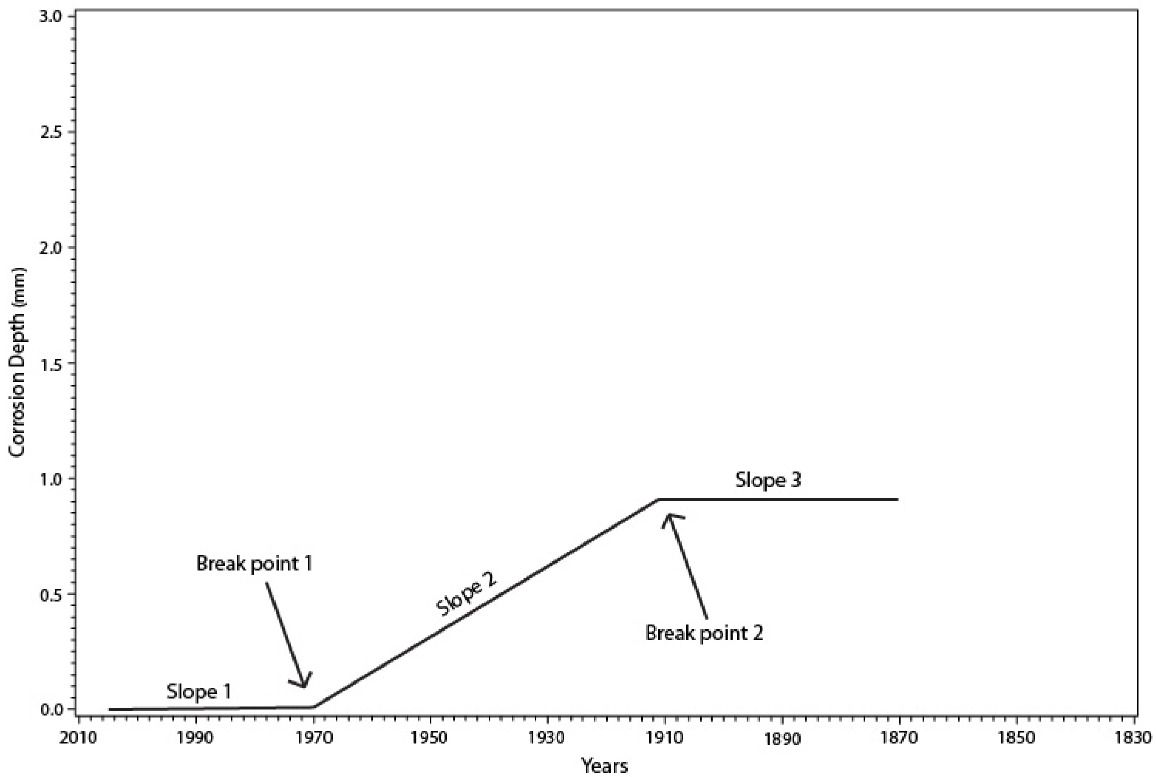

Figure 9. Example of SAS output break points and corrosion rates for each cemetery.

3.5.2 GIS spatial analysis

Cemetery corrosion rates and break points taken from the SAS output were used to plot spatial and temporal distribution of acidification in ArcMap (ArcGIS® version 10). Data were mapped using the Geostatistical Analyst Geostatistical Wizard tool with the ordinary kriging function. Cemetery corrosion rates were only used where gravestone data existed within the cemetery. Spatial coverage would be focused to cemeteries within the Black Country and temporal slices would be in ten-year increments (e.g. 2010, 2000, 1990, etc.).

3.6 Calculating Atmospheric Concentrations from Acid Deposition

Acid deposition rates can be converted to atmospheric concentrations if the atmospheric residence time and the height of the air column are known. The simplest approach is to use a steady-state box model where atmospheric concentrations (q) is related to source/sink rate (S), residence time (τ), and height of the air column (V) by the relation

$$q = S\tau/V.$$

In the steady-state box model, source and sink rates are in equilibrium. Modern atmospheric concentrations of SO_2 have been measured over the past 20 years as a part of the Automatic Urban and Rural Monitoring Network (AURN), UK. Modern acid deposition rates, from the 2010 dataset and 2005-2008 dataset (H. D. Mooers, unpublished data), were used as the sink rates to calculate the residence time. The height of the air column was then estimated. Most domestic smoke stacks are on the order of ten meters high, whereas industrial stacks are generally taller (on the order of 30 meters). As wind turbulence mixes the atmosphere, an assumed air column height of 500 meters and 5000 meters was used in this calculation.

4. Results

All cemetery locations are shown in Figure 10. Sites visited by Mooers and revisited in the 2010 study were JQK, JQW, SAN, SHI, and SOA. Cemetery information for the 2010 dataset and 2005-2008 dataset (H. D. Mooers, unpublished data) are summarized in Table 5.

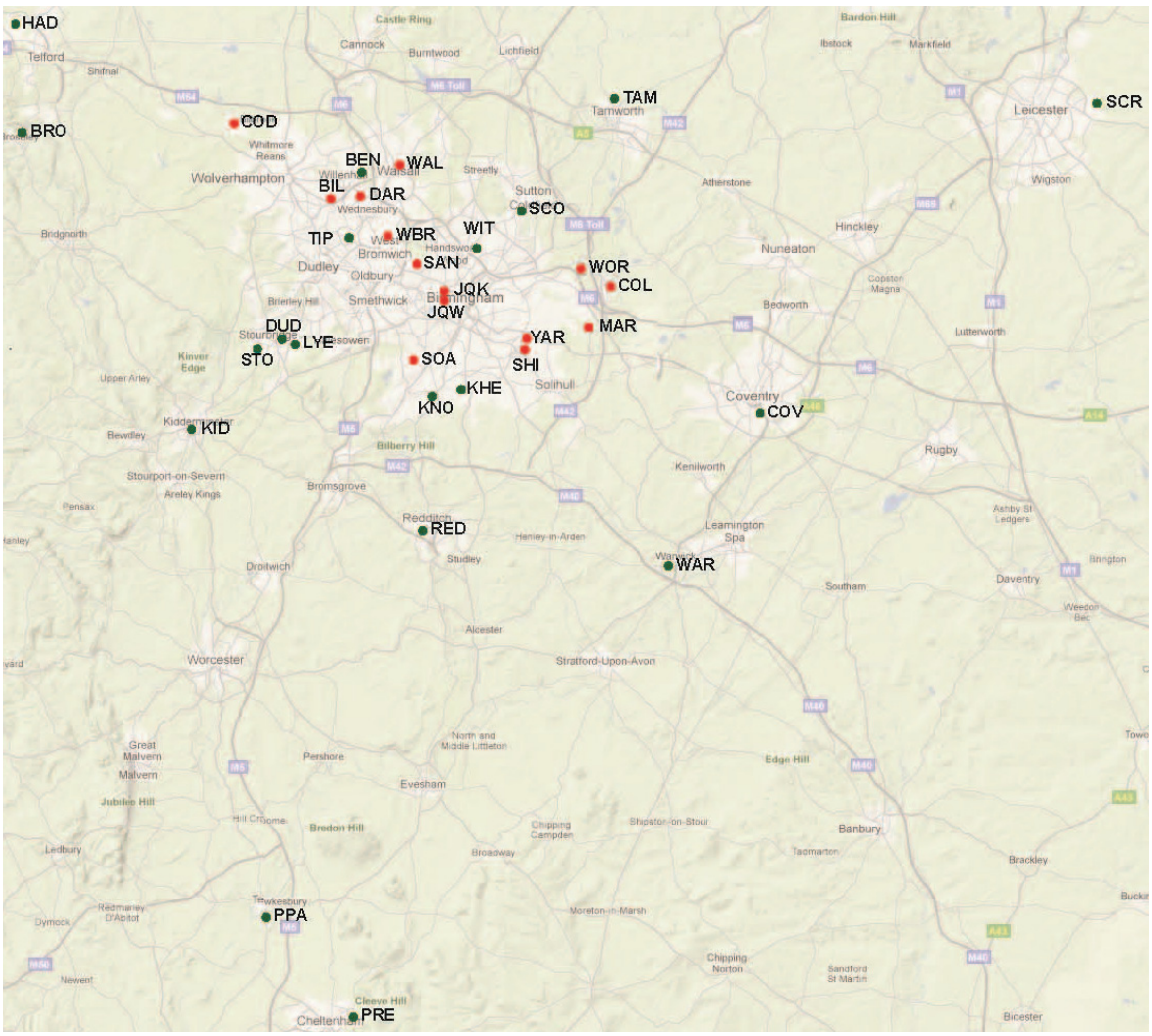

Figure 10. Spatial distribution of cemetery locations for the 2005-2008 dataset (H. D. Mooers, unpublished data) and the 2010 dataset. Green: sites visited by Mooers (unpublished data) in 2005-2008, and red: cemetery sites visited in 2010.

Table 5. Cemetery location: name, neighborhood, district, and country/metropolitan district divisions interpreted from Ordnance Survey Maps (2006a-g).

Cemetery ID	Cemetery name	Neighborhood	District	County
BEN		Bentley	Walsall	Walsall
BIL	Bilston Cemetery	Bilston	City of Wolverhampton	Wolverhampton
BRO		Brosely	Bridgnorth District	Shropshire
COD	Saint Nicholas Churchyard	Codsall	South Staffordshire	Staffordshire
COL	Coleshill Parish Church/Cemetery	Coleshill	North Warwickshire	Warwickshire
COV	London Road Cemetery	Coventry	Coventry	Coventry
DAR	Fallings Heath Cemetery	Darlaston	Sandwell	Sandwell
DUD	Scot's Green Cemetery	Dudley	Dudley	Dudley
HAD		Hadley	Telford and Wrekin	Telford and Wrekin
JQK	Key Hill Cemetery	Jewellery Quarter	Birmingham	Birmingham
JQW	Warstone Lane Cememtery	Jewellery Quarter	Birmingham	Birmingham
KHE	Brandwood End Cemetery	Kings Heath	Birmingham	Birmingham
KID		Kidderminster	Wyre Forest	Worcestershire
KNO	Saint Nicholas Cemetery	Kings Norton	Birmingham	Birmingham
LYE		Lye	Dudley	Dudley
MAR	Marston Green Burial Grounds	Marston Green	Solihull	Solihull
PPA		Priors Park	Tewkesbury	Gloucestershire
PRE		Prestbury	Cheltenham	Gloucestershire
RED		Redditch	Redditch	Worcestershire
SAN	Handsworth Cemetery	Sandwell	Birmingham	Birmingham
SCO		Sutton Coldfield	Birmingham	Birmingham
SCR	All Saints Church	Scraptoft	Charwood	Leicestershire
SHI	Robin Hood Cemetery and Crematorium	Shirley	Solihull	Solihull
SOA	Lodge Hill Cemetery and Crematorium	Selly Oak	Birmingham	Birmingham
STO	Stourbridge Crematorium	Stourbridge	Dudley	Dudley
TAM		Tamworth	Tamworth	Staffordshire
TIP	Tipton Cemetery	Tipton	Sandwell	Sandwell
WAR		Warwick		Warwickshire
WAL	Ryecroft Cemetery	Walsall	Walsall	Walsall
WBR	Heath Lane Cemetery	West Bromwich	Sandwell	Sandwell
WIT		Witon	Birmingham	Birmingham
WOR	Saint Peter and Saint Paul Parish Church	Water Orton	North Warwickshire	Warwickshire
YAR	South Yardley Cemetery and Crematorium	South Yardley	Birmingham	Birmingham

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The measured gravestone corrosion values and corresponding information for all cemeteries are tabulated in Appendix A. As an example, Figure 11a illustrates unadjusted corrosion measurements for all cemeteries in the 2010 study. Figure 11b shows the temporal variability of corrosion for individual gravestones within a single cemetery (SAN). It is the relationship between corrosion measurements on individual gravestones and the cemetery variables that provides the necessary information needed to make adjustments. These adjustments normalize the data for cemetery variability.

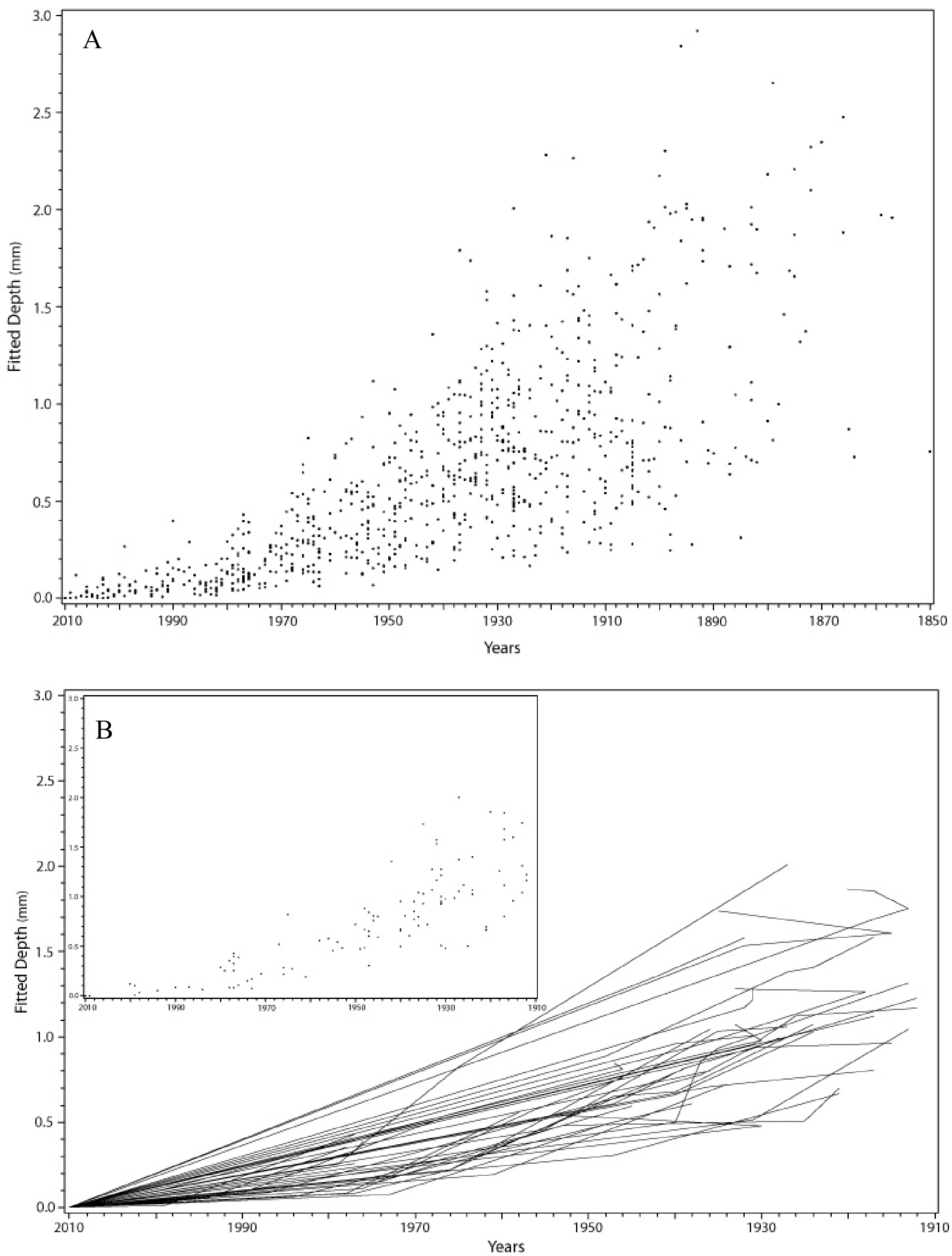


Figure 11. (A) Unadjusted/raw corrosion measurements for all cemeteries in the 2010 dataset plotted as individual inscription points. (B) 2010 data for SAN plotted as individual gravestone corrosion, lines represent corrosion slopes for each stone within SAN cemetery.

4.1 Statistical Analysis of Variable Effects

Results of the multiple linear regression model indicated all variables assessed are statistically significant (p-values ≤ 0.5) with corrosion measurements (Table 6). Because all variables are statistically significant, variables must then be assessed to determine whether gravestone corrosion is dependent upon those variables.

Table 6. P-value results for cemetery variables assessed with SAS.

Variable	**P-value significance**
Tree cover	0.0267
Elevation	< 0.0001
Texture	< 0.0001
Color	0.0020

4.1.1 Tree Cover

JQK, JQW, SOA, and YAR cemeteries were selected to assess the effects of tree cover on corrosion measurements because substantial portions of these cemeteries were covered by trees. Because of the close proximity (500 meters), JQK and JQW were considered to be one cemetery when assessing the influence of cemetery variables on corrosion measurements. The only readily identifiable difference between JQK and JQW is the extensive tree cover at JQK. Figure 12 shows distinctly that lack of tree cover results in higher corrosion rates than gravestones under tree cover, reference Table 7 for the number of gravestones assessed under tree cover at JQK and JQW.

Unadjusted corrosion rates for all cemeteries in the 2010 dataset are shown in Figure 13. Gravestone corrosion rates under tree cover at these three cemeteries (JQK/JQW, SOA, and YAR) is approximately ten percent less than gravestone in open sites. In JQK and JQW the effects of tree cover on corrosion measurements resulted in a 20 percent decrease in corrosion when gravestones resided under tree cover.

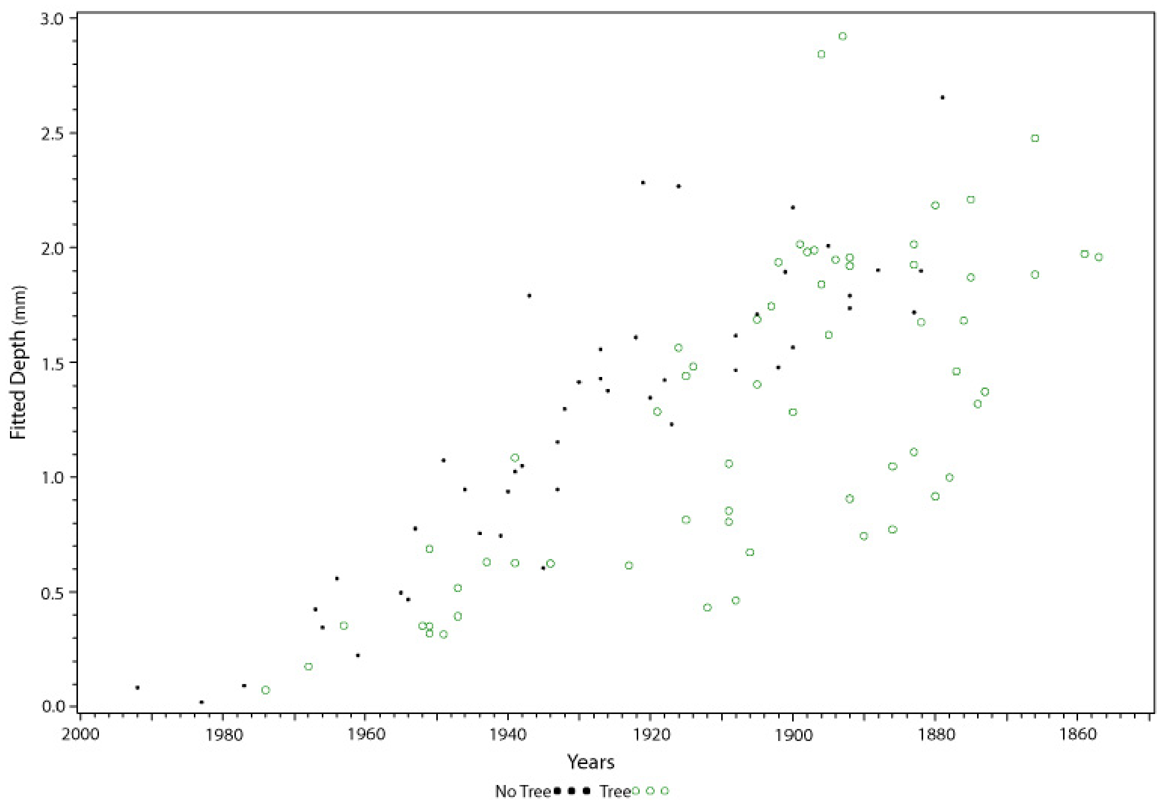


Figure 12. JQK and JQW gravestone inscription distribution of unadjusted corrosion measurements for tree cover and no tree cover. Figure represents gravestone inscription measurements for the 2010 dataset. The 2005-2008 dataset had no information on tree cover for the measurements gathered at these cemeteries.

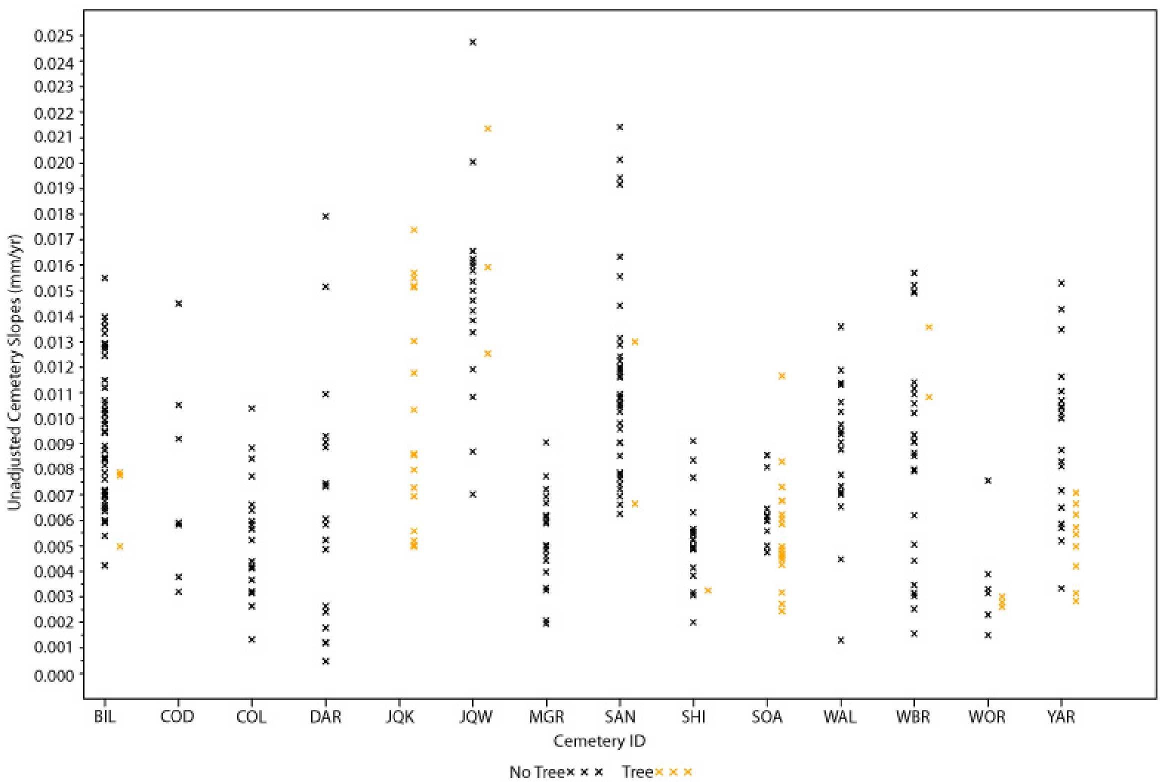


Figure 13. Unadjusted corrosion rates for tree cover within all 2010 cemetery locations. Because of the close proximity of JQK and JQW the corrosion rates for them cemeteries could be combined to represent the largest number of tree covered and no tree covered stones in one area. SOA and YAR also represent cemeteries where a number of tree and no tree information were collected within the cemetery.

4.1.2 Elevation

Elevation data were limited to three cemeteries: JQK, JQW, and SAN (Figure 14). Relative topographic highs within a single cemetery experience greater corrosion than low lying areas. However, this relationship may be more complicated than initially assessed. Local elevation differences within a single cemetery are characteristic of the physical setting and thus may affect corrosion rates. The ANOVA model determined an interaction between tree cover and elevation; the effect of tree cover was dependent on local elevation differences within a single cemetery (Figure 15). The presence of an interaction means all combinations of the two X variables should be adjusted. For example, if the effect of tree cover (Y and N) is different at high elevations (H) than at low elevations (L), the adjustment would need to be made for combinations rather than just a single scenario, such as Y and H.

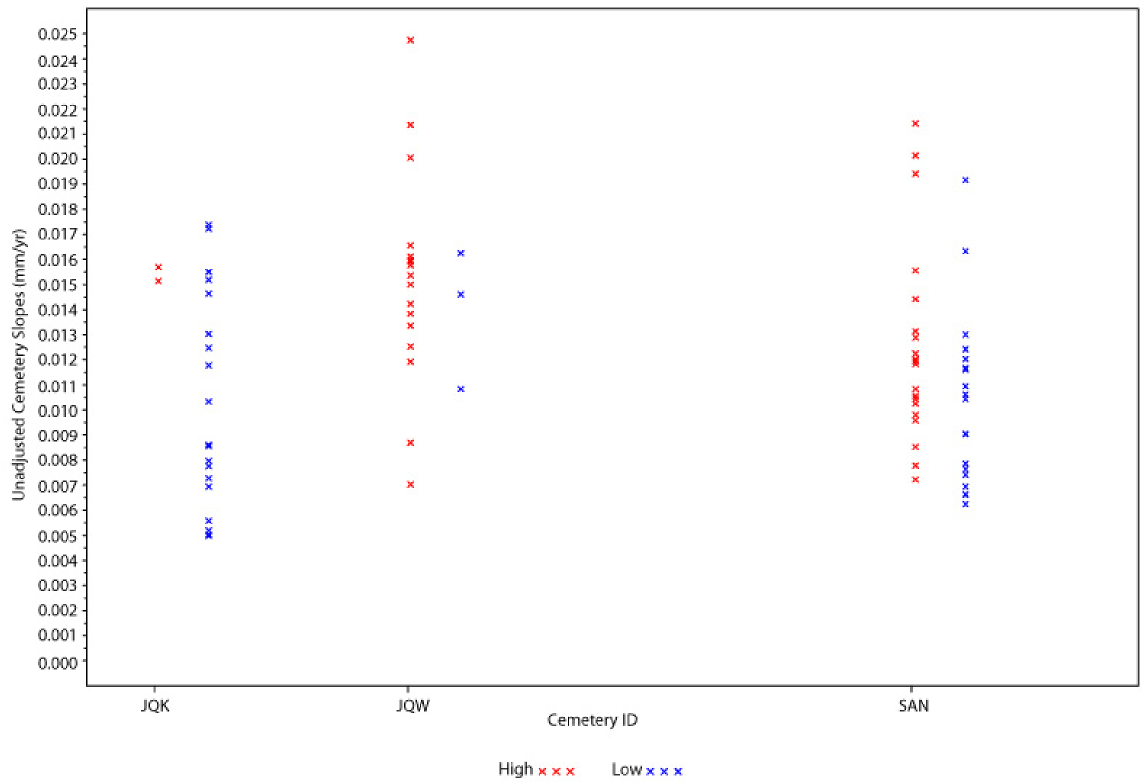


Figure 14. Distribution of unadjusted corrosion rates for local elevation differences within cemeteries: JQK, JQW, and SAN. Elevation data was lacking for all 2010 cemetery locations not plotted above. Most cemeteries within the 2010 dataset and 2005-2008 dataset did not have elevation differences within a single cemetery greater than a few meters.

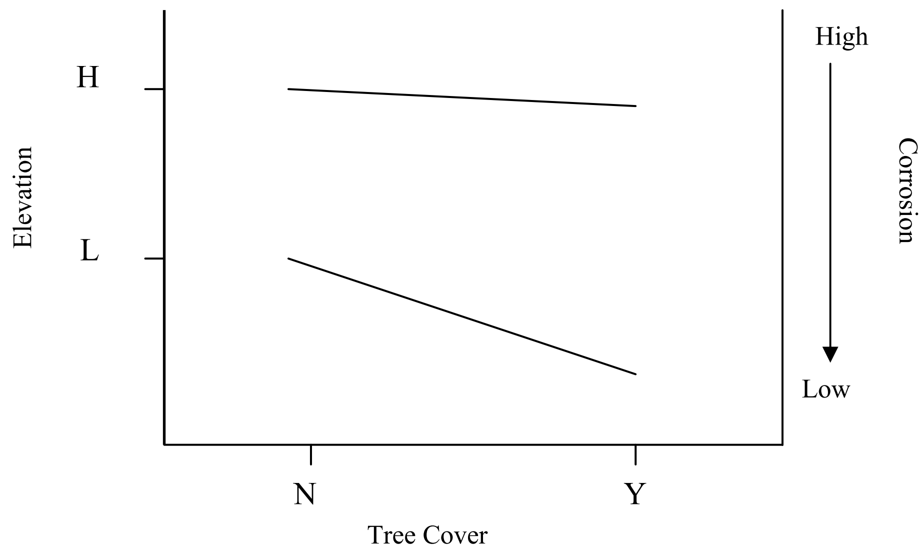


Figure 15. Representation of the relationship (ANOVA variable interaction) between tree cover and elevation. For gravestone corrosion measurements, the effects of tree cover and no tree cover at high elevations are similar. Whereas, gravestone corrosion measurements with no tree cover at low elevations experience greater corrosion than tree cover at low elevation.

4.1.3 Gravestone color

The distribution of unadjusted gravestone corrosion rates for color is represented in Figure 16. Although the relationships among color and gravestone corrosion measurements are statistically significant (p-value ≤ 0.5); the meaning of this relationship is unclear. The original working hypothesis was that gravestones with high corrosion rates would be white because material loss was too great for algae/lichen to establish on the surface, while less corroded gravestones would be darkly colored. However, if the above stated relationships are true, then areas with little impact from pollution, such as MAR, SHI, and WOR, would have predominately dark colored gravestones. This is not the case; rather there are roughly the same proportions of light to dark stones at each cemetery assessed in the 2010 study. Gravestone color is not an inherent physical property of the stone; rather it appears to be a result of the weathering processes.

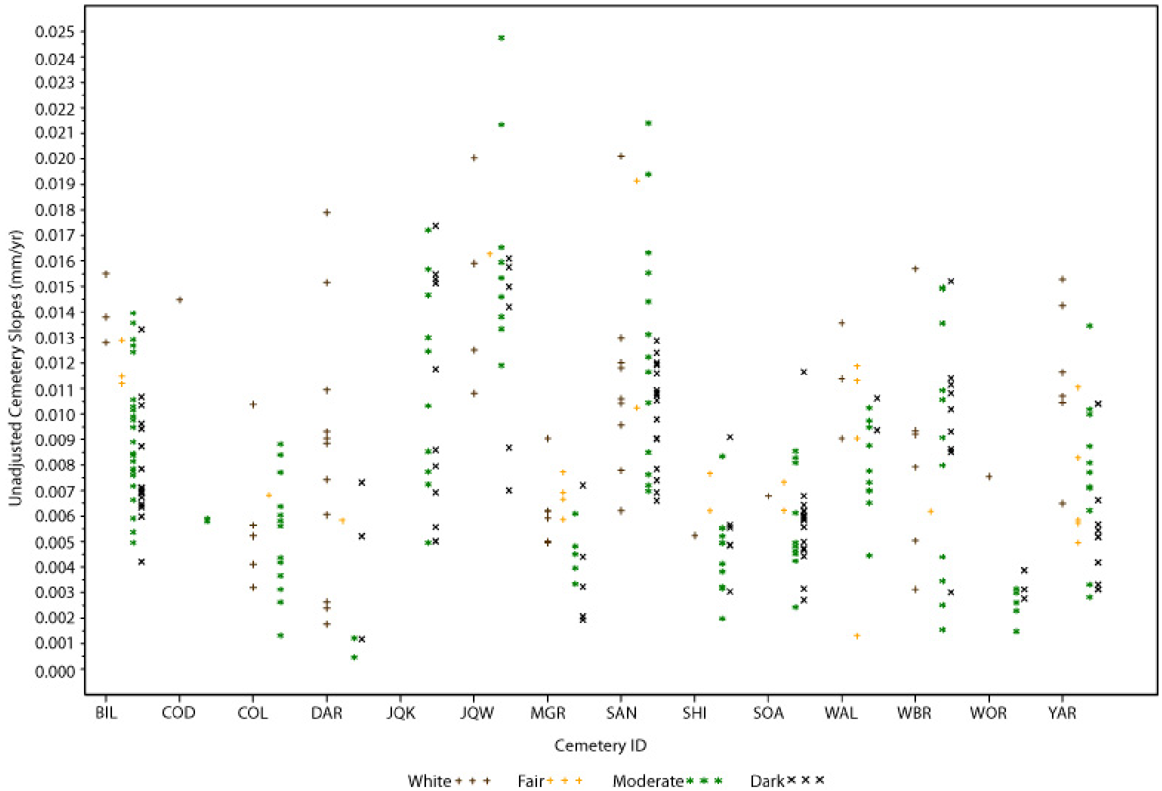


Figure 16. Distribution of color for the unadjusted gravestone corrosion data in the 2010 dataset.

4.1.4 Gravestone texture

The data and SAS analyses (Figure 17) show rougher gravestones weather more rapidly than smooth textured gravestones. Gravestone texture is an inherent physical property of the stone which manifests itself as the marble weathers. For example, the resistant recrystallized fractures within a marble gravestone become more visible as the surface corrodes resulting in a rough textured gravestone surface.

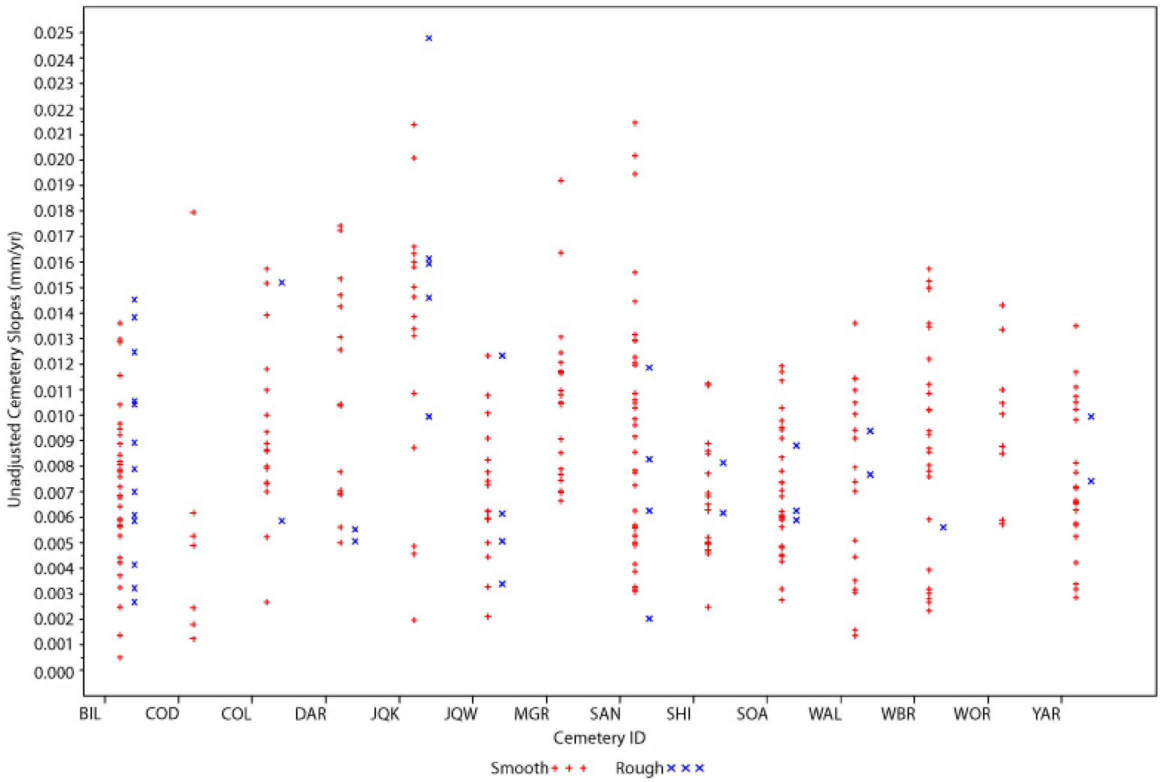


Figure 17. The distribution of corrosion rates from the gravestone texture variable; cemeteries assessed during the 2010 study.

4.2 Dataset Adjustments

Considering the aforementioned variable assessments, adjustments for the 2010 dataset should be for tree cover, elevation, and texture. However, elevation data is lacking in all but three cemeteries (JQK, JQW, and SAN); most cemeteries simply do not have significant topographic variation. If an adjustment for the interaction between elevation and tree cover were applied to gravestones with elevation information and only for tree if elevation information was missing, the dataset would be incomparable regionally. Therefore, adjustments to the gravestone corrosion measurements were made only for tree cover and gravestone texture. Because there is no interaction between tree cover and texture, corrosion measurements were adjusted without having to consider the special effects of particular combinations of tree cover and texture. The SAS model gives the natural log of the corrosion rate as:

Ln (corrosion rate) = - 2.27 + 0.1078 (if tree = N) + 0.1090 (if texture = R). (1)

Tree cover and texture variables similarly effect gravestone corrosion as shown by equation (1). The presence of tree cover lowers the gravestone corrosion rates by approximately ten percent, while rough textured gravestones increase corrosion rates by ten percent. If tree cover is 'Y' and texture is 'S' the adjustment would increase the corresponding gravestone corrosion measurement. For a list of number of gravestone inscriptions within a single cemetery fulfilling variable criteria refer to Table 7. No adjustment was applied to measurements from the 2005-2008 dataset (H. D. Mooers, unpublished data) unless variable information was available for adjustment.

To calculate corrosion rates for each cemetery, first corrosion measurements for individual gravestone inscriptions are plotted as raw values. Equation (1) is used to adjust corrosion measurements for the tree and texture variables. Refer to Figure 18a for an example of gravestone adjustment. This adjustment decreased the corrosion measurements because variable information for this gravestone was 'N' and 'R'. Following tree and texture variable adjustments to the 2010 dataset and 2005-2008 dataset (H. D. Mooers, unpublished data), predicted corrosion rates and break points were determined for each gravestone using the non-linear model (Figure 18b). The fitted lines derived from the non-linear model for each gravestone was used to determine the overall cemetery slope and break points (Figure 19). Figure 20 shows the cemetery corrosion rate with break point assessment overlain by the adjusted gravestone corrosion measurements.

This plot serves as a check for cemetery corrosion rate and break point placement validity. Figure 21 shows the cemetery corrosion rate and break point assessment overlain by the adjusted gravestone corrosion rates. Not all corrosion rates and break point assessments are completely reliable because data does not equally span over the past 160 years (Table 8). For this same reason the non-linear model was unable to process the slopes and break point assessment for RED, TAM, and WAR. Cemetery corrosion rates and break points were only plotted for available data. For example, the oldest inscription measured at MAR was 1962; therefore break point assessment and corrosion rates were only determined by the non-linear model from 1962-2010.

Table 7. Collected variable information for the 2010 dataset and 2005-2008 dataset. * No adjustment was made to data within this cemetery because no variable information was collected.

Cemetery ID	Year Measured	Stone #	Inscription #	Tree		Texture			Color			Elevation	
				N	Y	R	S	W	F	M	D	H	L
BEN*	05	9	17	.	.	.	.	.	.	.	.	.	.
BIL	10	47	124	44	3	13	34	3	3	24	16	.	.
BRO*	06	13	24	.	.	.	.	.	.	.	.	.	.
COD	10	7	16	7	.	.	7	1	.	2	.	.	.
COL	10	20	47	20	.	2	18	5	1	14	.	.	.
COV*	05	6	10	.	.	.	.	.	.	.	.	.	.
DAR	10	18	45	18	.	2	16	11	1	2	3	.	.
DUD*	07	11	19	.	.	.	.	.	.	.	.	.	.
HAD*	06	11	21	.	.	.	.	.	.	.	.	.	.
JQK	06, 10	26	87	.	17	5	16	.	.	10	10	2	19
JQW	05, 06, 10	30	82	17	3	4	16	4	1	9	6	17	3
KHE	06	14	43	.	3	.	.	.	.	.	.	.	.
KID*	05	9	15	.	.	.	.	.	.	.	.	.	.
KNO*	05, 06	12	27	.	.	.	.	.	.	.	.	.	.
LYE*	05	6	14	.	.	.	.	.	.	.	.	.	.
MAR	10	20	40	20	.	.	20	.	.	.	.	.	.
PPA*	05	6	15	.	.	.	.	.	.	.	.	.	.
PRE*	05	5	13	.	.	.	.	.	.	.	.	.	.
RED*	05	8	11	.	.	.	.	.	.	.	.	.	.
SAN	08, 10	54	142	50	3	5	36	11	7	17	18	27	26
SCO*	05	7	18	.	.	.	.	.	.	.	.	.	.
SCR*	08	7	12	.	.	.	.	.	.	.	.	.	.
SHI	05, 10	26	60	19	1	2	18	1	2	11	6	.	.
SOA	06, 08, 10	81	186	11	25	3	27	8	3	17	26	.	8
STO*	07	18	39	.	.	.	.	.	.	.	.	.	.
TAM	05	7	7	.	1	.	.	.	.	.	.	.	.
TIP*	05	7	16	.	.	.	.	.	.	.	.	.	.
WAL	10	20	45	20	.	2	18	3	4	11	2	.	.
WAR*	05	5	7	.	.	.	.	.	.	.	.	.	.
WBR	10	27	63	25	2	1	26	6	1	11	9	.	.
WIT*	06	10	23	.	.	.	.	.	.	.	.	.	.
WOR	10	9	19	6	3	.	9	1	.	5	3	.	.
YAR	10	30	91	21	9	2	28	6	5	11	8	.	.

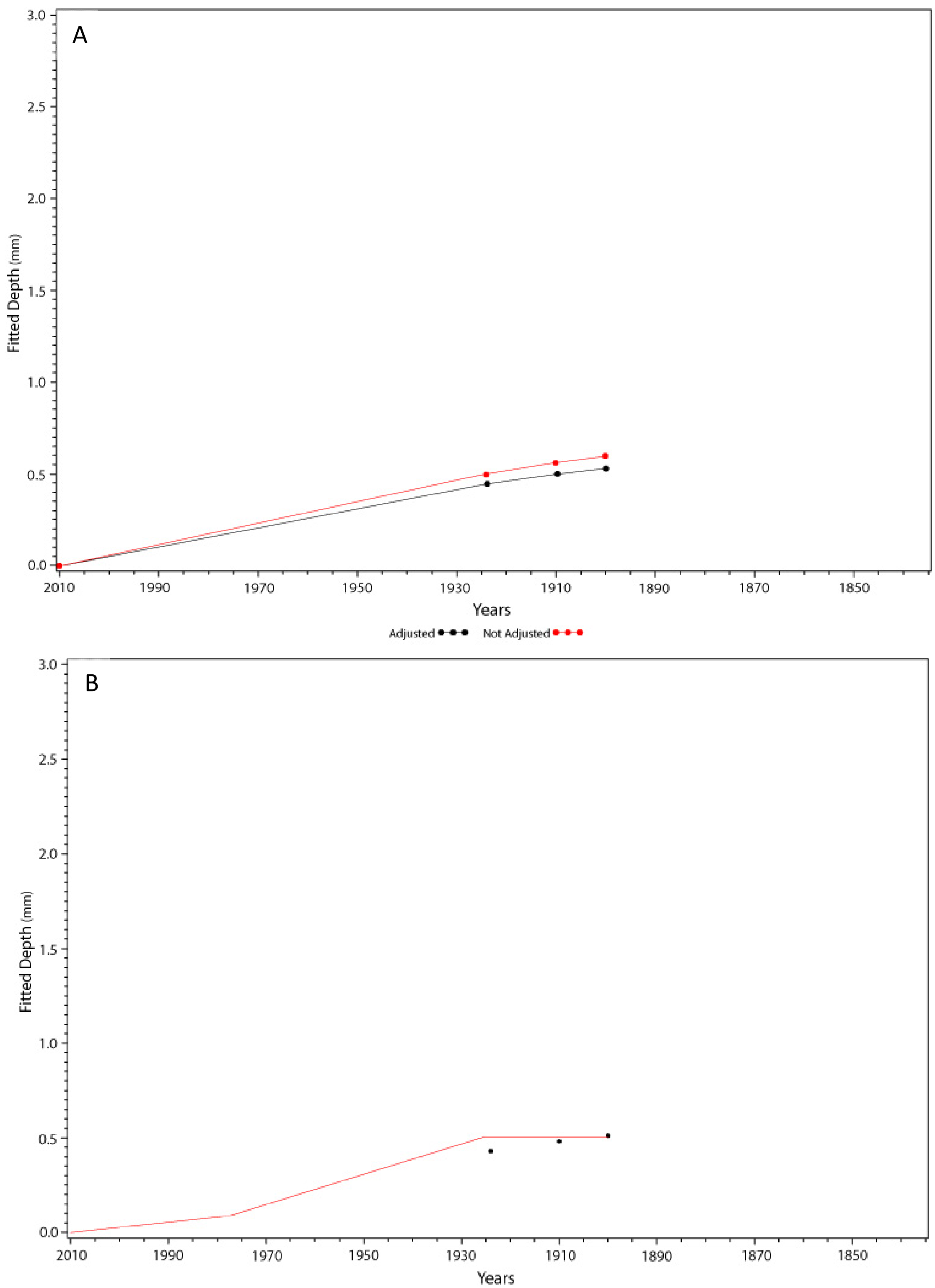


Figure 18. (A) Unadjusted and adjusted corrosion measurements for BIL gravestone ten. The adjustment factor decreases the corrosion rate because the gravestone is both rough and located under tree cover. (B) Predicted gravestone corrosion rates and break points are derived from the non-linear model in SAS.

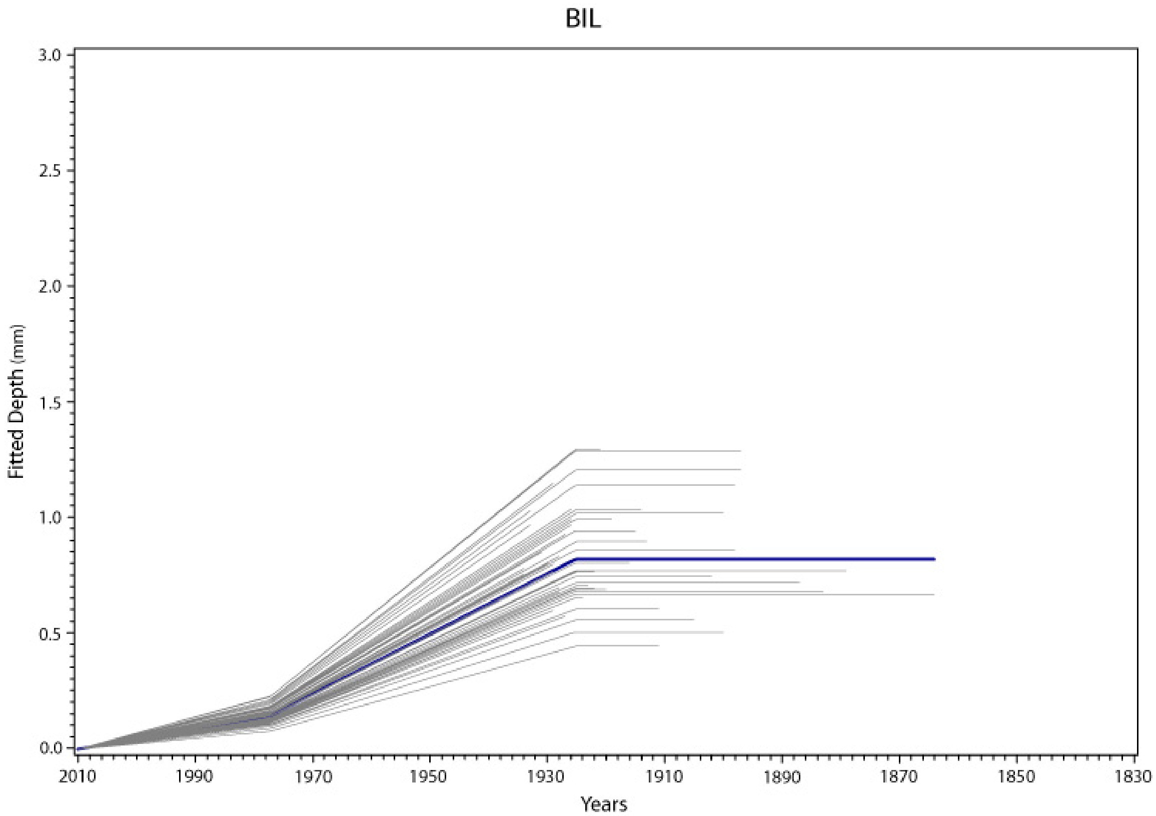


Figure 19. Cemetery corrosion rate and break points overlain by individual gravestone corrosion rates and break points for BIL.

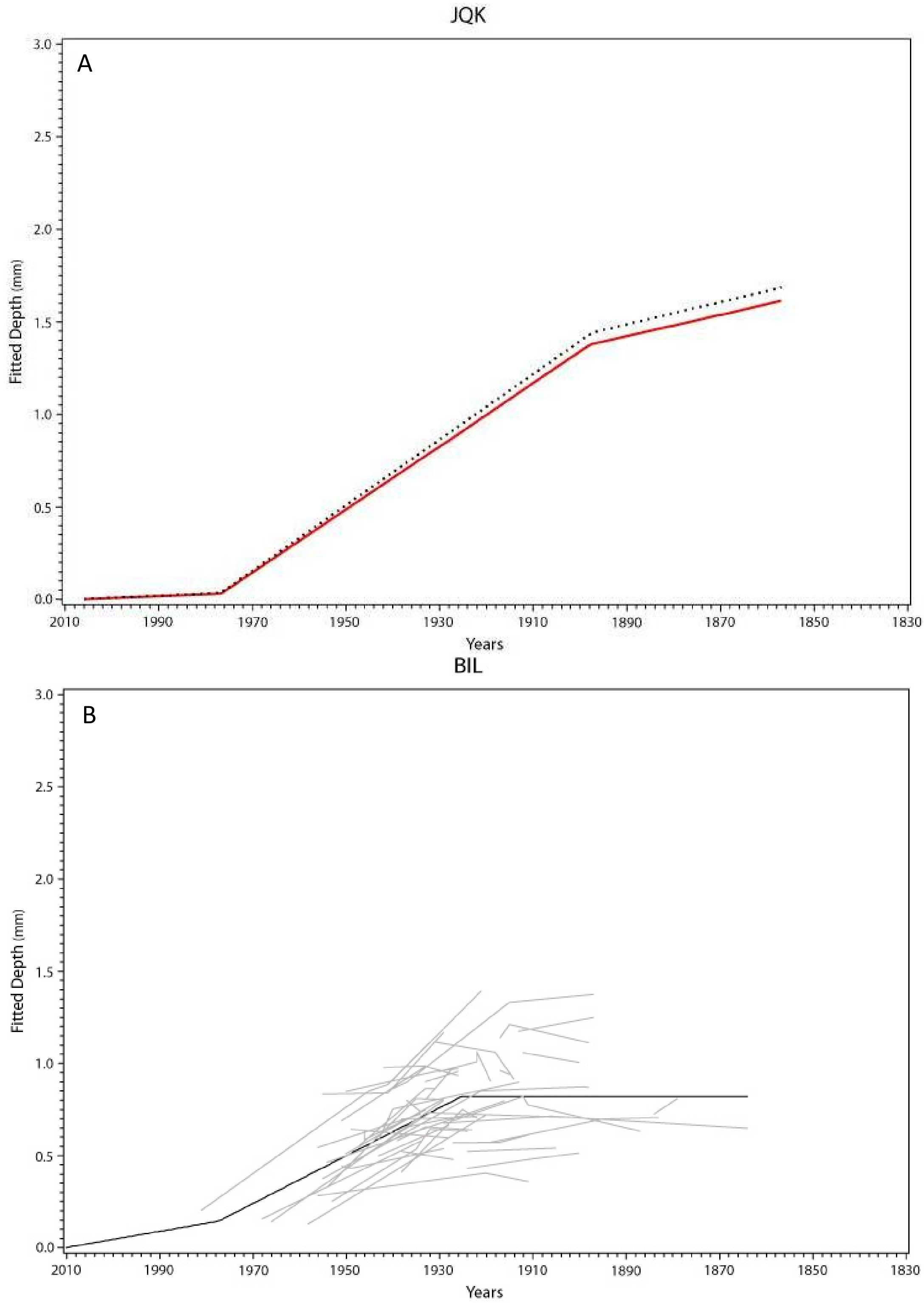


Figure 20. (A) Example of the adjustment applied to the cemetery slope and break point analysis for tree cover and texture; unadjusted corrosion rate (red) and adjusted corrosion rate (dashed line). (B) Cemetery corrosion rates and break points for BIL overlain with adjusted gravestone corrosion measurements.

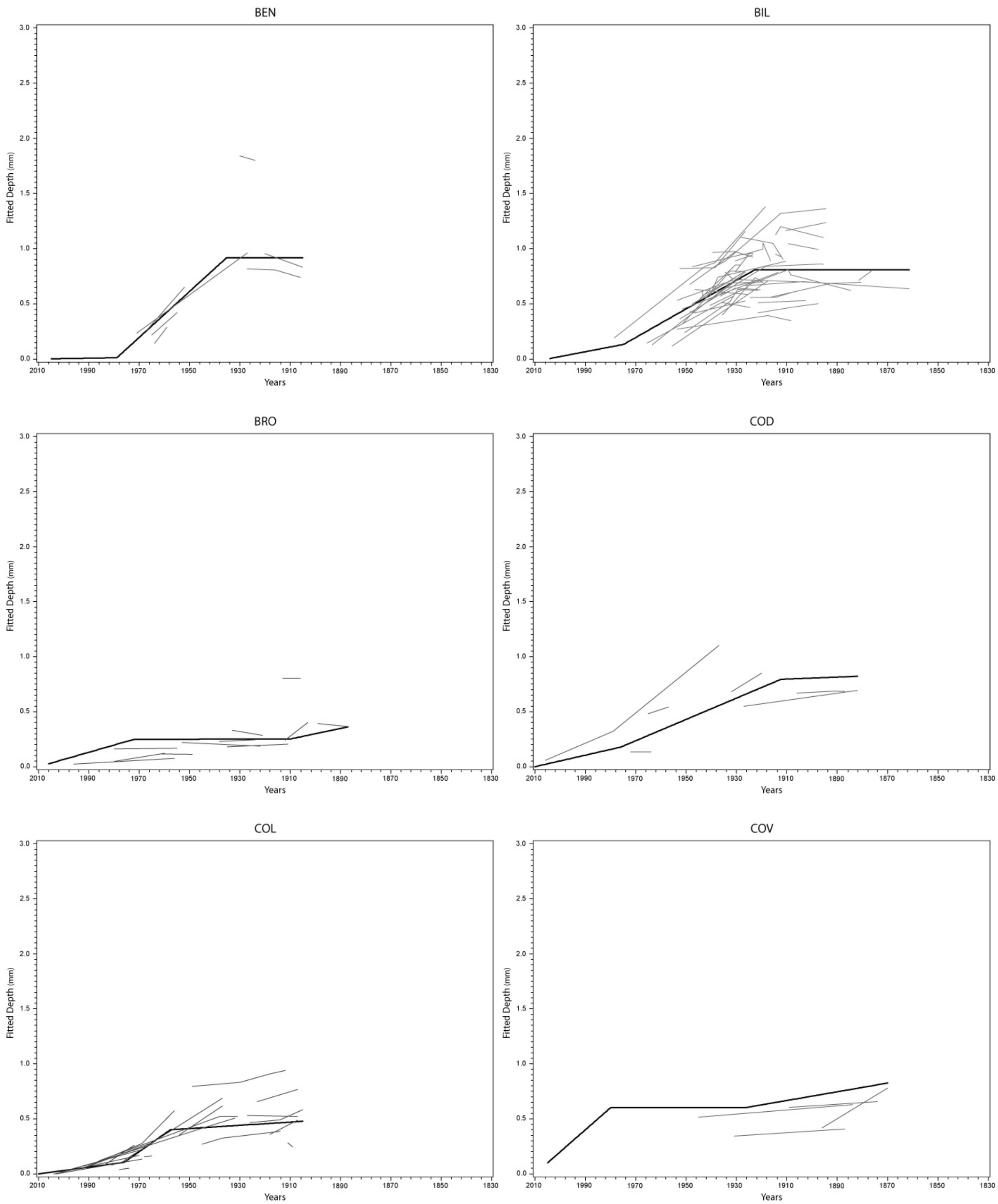


Figure 21. Break point analyses and slope readings for three major acid deposition environments as assessed with the non-linear model in SAS. Cemetery corrosion rates (black) overlain by adjusted individual gravestone corrosion rates within the cemetery (grey).

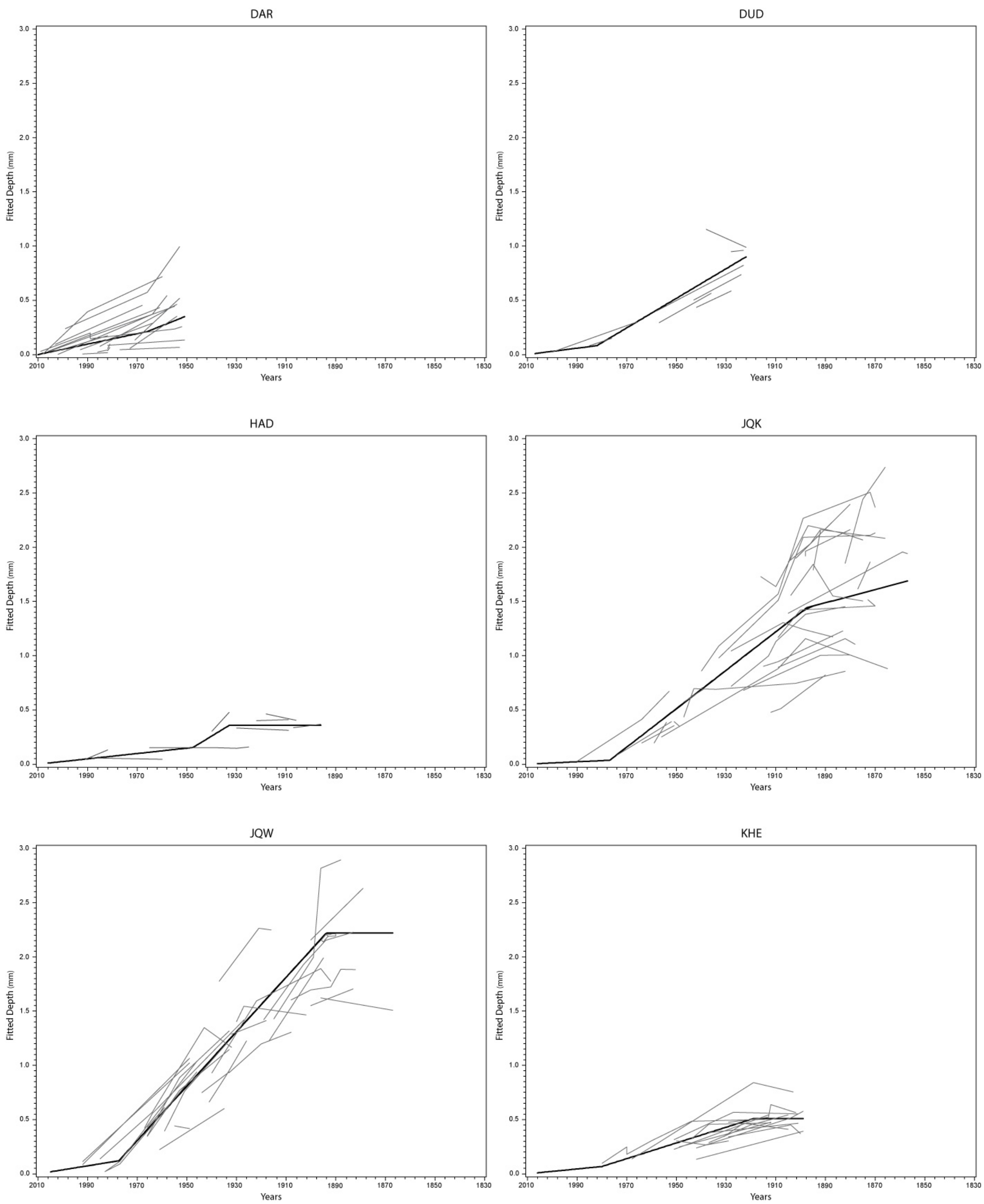
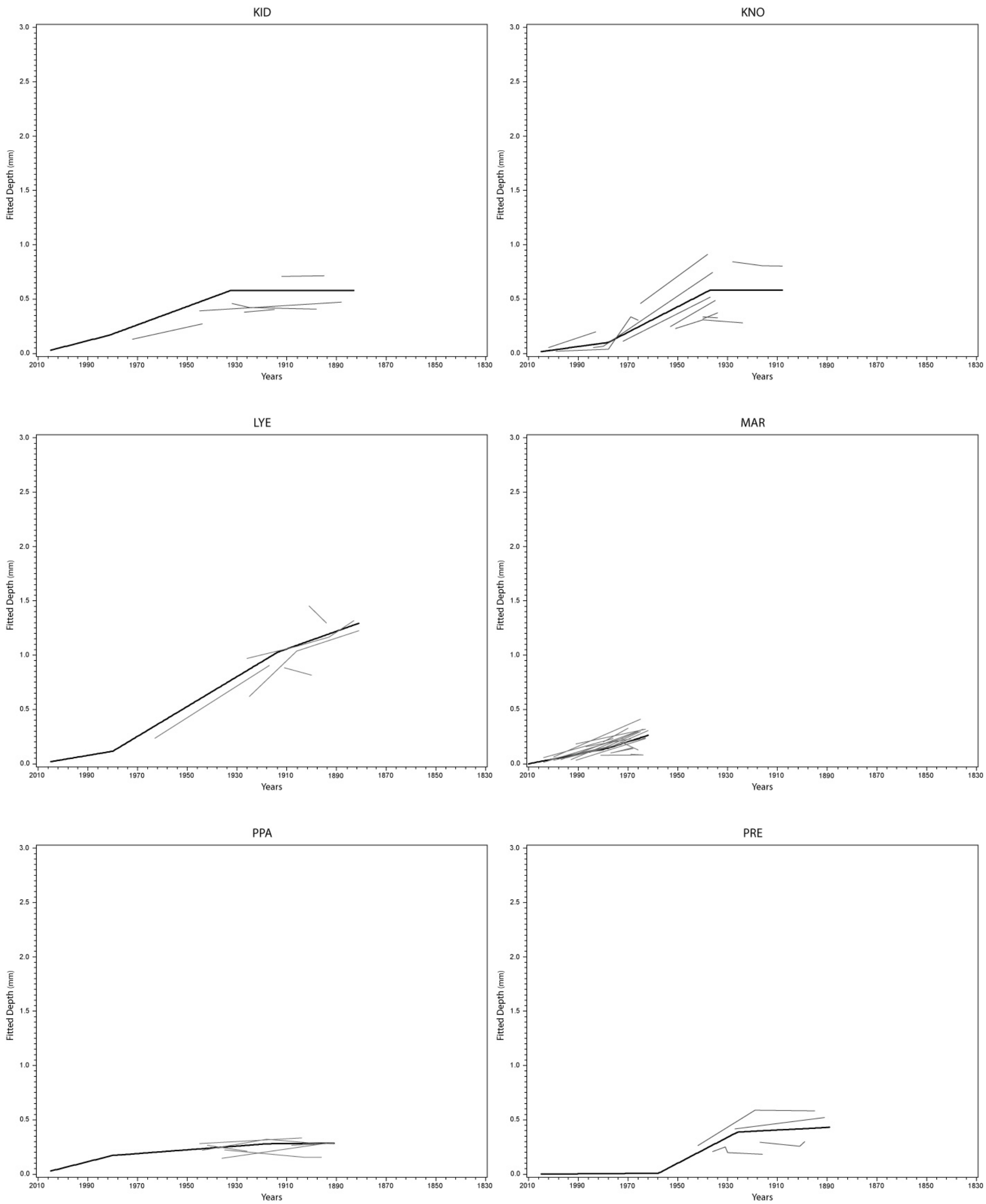


Figure 21. Continued.



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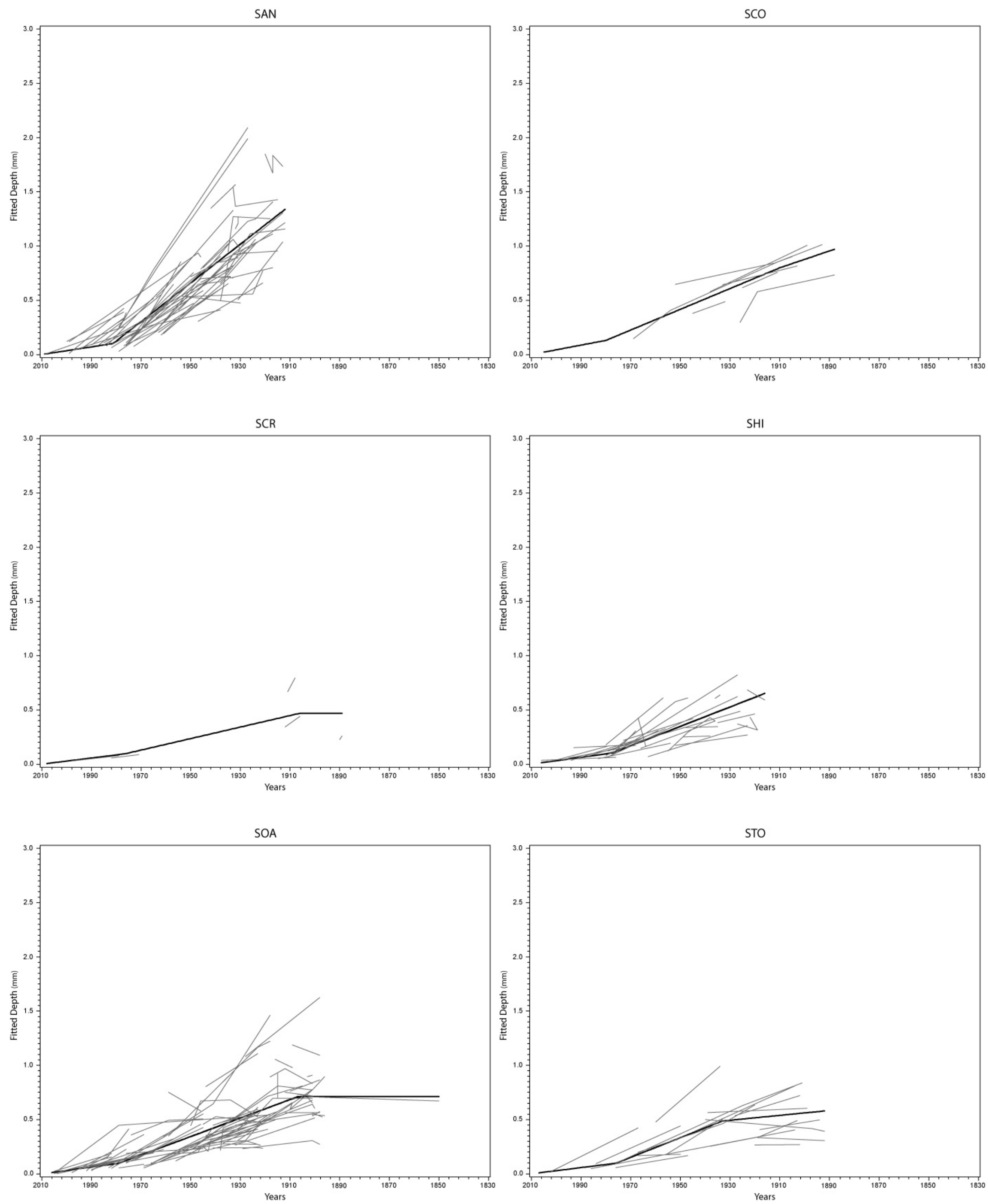

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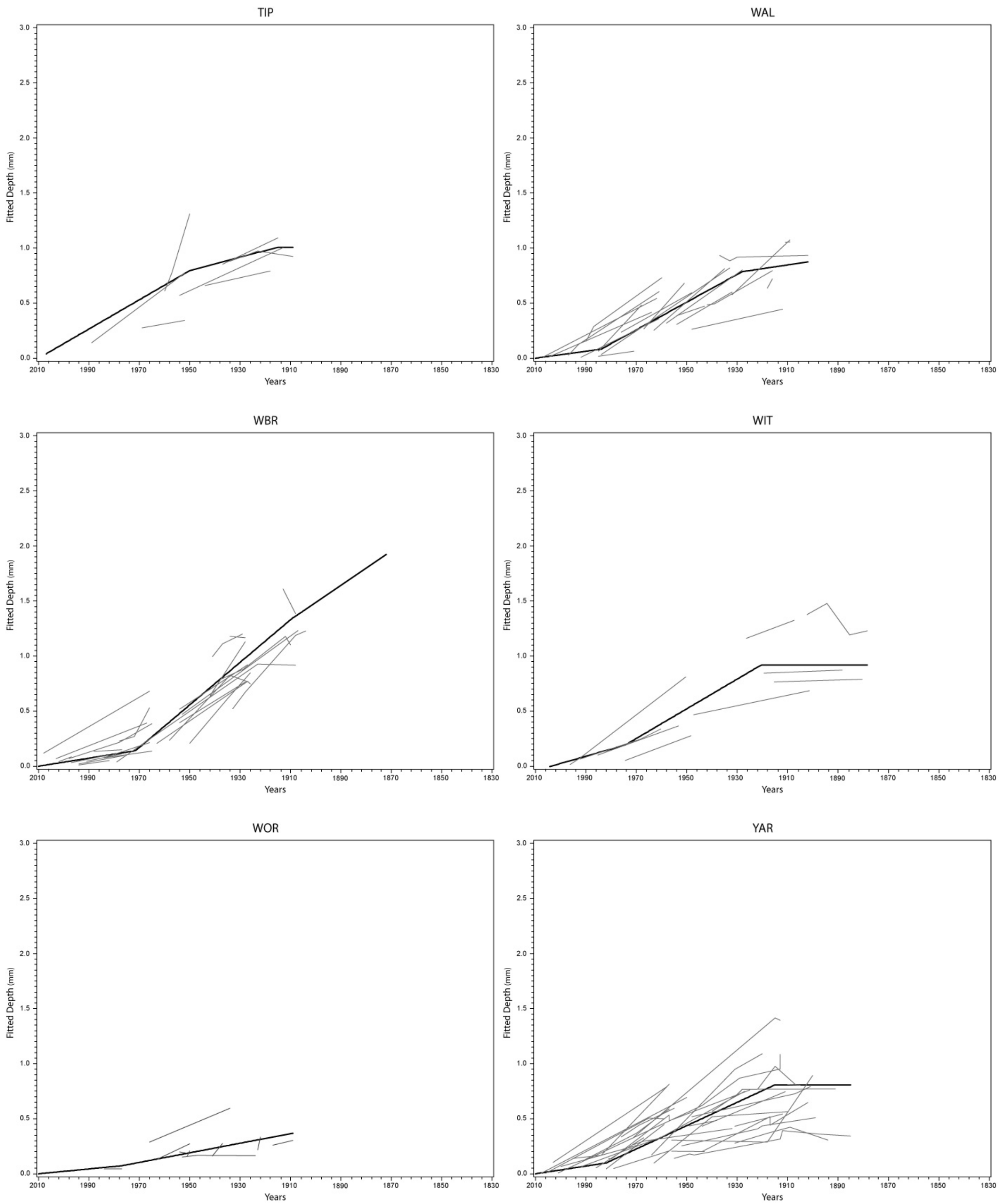

Figure 21. Continued.

Table 8. Break point analyses and associated cemetery corrosion rate results from SAS. Blanks represent corrosion rates unreliable because of a lack of stone inscription points. Inscription range excludes the inserted zero corrosion measurement for 2010 and shows range of years in which data was collected.

Cemetery ID	Stone #	Inscrip. #	Inscrip. Range	Break 1 (years ago)	Break 2 (years ago)	Slope 1 (mm/yr)	Slope 2 (mm/yr)	Slope 3 (mm/yr)
BEN	9	17	1971-1905	31.09	74.68	0.000355	0.020777	3.55E-12
BIL	47	124	1981-1864	32.70	84.79	0.004373	0.012971	4.37E-11
BRO	13	24	1996-1887	37.81	99.93	0.006547	5.77E-05	0.004718
COD	8	16	2006-1882	34.00	97.75	0.005221	0.009685	0.000873
COL	19	47	2004-1905	34.00	52.37	0.003066	0.016124	0.001457
COV	6	10	1945-1870	29.99	83.32		2 E-10	0.003951
DAR	18	45	2009-1951	44.00	100.00	0.004804	0.009096	0.004563
DUD	11	19	2006-1922	27.95	100.00	0.002923	0.013632	0.002777
HAD	11	21	1991-1896	62.42	77.00	0.002452	0.013985	2.45E-11
JQK	26	87	1990-1857	33.17	112.55	0.001098	0.017713	0.006056
JQW	30	82	1992-1867	32.56	116.26	0.003689	0.025087	3.69E-11
KHE	14	43	1980-1899	29.87	91.00	0.002232	0.007233	2.23E-11
KID	9	15	1972-1883	28.85	77.37	0.005872	0.008431	5.87E-11
KNO	12	27	2002-1908	32.00	73.00	0.003172	0.011746	3.17E-11
LYE	6	14	1963-1881	30.04	96.41	0.003859	0.013736	0.008141
MAR	20	40	2004-1962	32.00	100.00	0.004496	0.007396	0.004271
PPA	6	15	1945-1891	30.01	92.00	0.005739	0.001728	0.000242
PRE	5	13	1942-1889	52.17	84.04	0.000162	0.011884	0.001187
SAN	54	142	2009-1912	28.64	100.00	0.003537	0.017843	
SCO	7	18	1969-1888	30.02	100.01	0.004343	0.00956	0.007763
SCR	8	12	1998-1889	33.47	104.00	0.002847	0.005301	2.85E-11
SHI	26	60	2006-1916	32.51	100.00	0.003172	0.008929	
SOA	80	186	2005-1850	30.76	103.16	0.003081	0.008515	3.08E-11
STO	18	39	2002-1892	34.00	76.89	0.002859	0.009075	0.002255
TIP	7	16	1989-1909	60.00	95.00	0.013259	0.00605	1.33E-10
WAL	20	45	2007-1902	26.00	82.00	0.00315	0.012563	0.003408
WBR	27	63	2008-1872	38.43	100.28	0.00365	0.019314	0.015598
WIT	10	23	1998-1880	34.00	2.05	0.006555	0.013467	6.56E-11
WOR	9	19	1984-1909	33.00	99.94	0.0022	0.004359	0.001967
YAR	30	91	2008-1885	28.00	95.00	0.003507	0.010589	3.51E-11

4.3 Spatial and Temporal Assessment of Corrosion

Because cemeteries RED, TAM, and WAR are located a considerable distance away from the concentration of cemeteries centered on Birmingham, the spatial and temporal reliability of the ArcMap kriging in the intervening areas is poor. Therefore, these cemeteries were not used in the spatial and temporal analysis of corrosion rate distribution in the West Midlands. The statistical model was also unable to determine accurate break points and gravestone corrosion rates needed to determine the cemetery break points and corrosion rate for these cemeteries. Data for RED, TAM, and WAR is limited to three gravestones, one gravestone, and three gravestones with multiple inscriptions, respectively. Additional data would need to be gathered from these cemeteries before reliable cemetery break points and corrosion rates could be determined.

Data used for the spatial and temporal analysis of the distribution of corrosion rates are shown in Table 9. JQW experienced the greatest amount of corrosion at 2.509 mm/100-yrs from 1900-1970. JQK, located 500 meters to the north of JQW, experienced approximately 30 percent less corrosion than its neighboring cemetery from 1900-1970. Cemeteries located in the Black Country, such as: BEN, BIL, COL, DUD, TIP, WBR, and WIT, also experience relatively high rates of corrosion prior to 1980 (Figure 22). A bull's-eye effect of high corrosion rates is centered on the Black Country from 1910 to 1980. Most cemeteries located in the Black Country experienced a decrease in corrosion from slope 2 to slope 1.

The default parameters were used in the kriging analysis of the Geostatistical Wizard. Diagonal trends shown in Figure 22 and Figure 23 are a factor of data limitations in sample size and proximity to neighboring cemeteries. Corrosion rates varied widely within the West Midlands. This wide variation over relatively small distances indicates that cemeteries reflect a localized acid deposition environment rather than exhibiting regional effects. As a result, regional corrosion rates are not well correlated.

Table 9. Adjusted cemetery corrosion rates used for ArcGIS® spatial and temporal analysis. Data reported in mm/100-yrs. Blank slots represent missing data not used in the spatial and temporal analysis. Numbers in red represent the end of a break point or change in rate of corrosion.

CemeteryID	2010	2000	1990	1980	1970	1960	1950	1940	1930	1920	1910	1900	1890	1880	1870	1860	1850
BEN	0.04	0.04	0.04	0.04	2.08	2.08	2.08	2.08	0.00	0.00	0.00						
BIL	0.44	0.44	0.44	0.44	1.30	1.30	1.30	1.30	1.30	0.00	0.00	0.00	0.00	0.00	0.00		
BRO	0.66	0.66	0.66	0.66	0.01	0.01	0.01	0.01	0.01	0.01	0.47	0.47	0.47				
COD	0.52	0.52	0.52	0.52	0.10	0.10	0.10	0.10	0.10	0.10	0.09	0.09	0.09				
COL	0.31	0.31	0.31	0.31	1.61	1.61	0.15	0.15	0.15	0.15	0.15						
COV				0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.40	0.40	0.40	0.40	0.40		
DAR	0.48	0.48	0.48	0.48	0.48	0.91											
DUD	0.29	0.29	0.29	1.36	1.36	1.36	1.36	1.36	1.36								
HAD	0.25	0.25	0.25	0.25	0.25	0.25	0.25	1.40	0.00	0.00	0.00	0.00					
JQK	0.11	0.11	0.11	0.11	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	0.61	0.61	0.61	0.61	
JQW	0.37	0.37	0.37	0.37	2.51	2.51	2.51	2.51	2.51	2.51	2.51	2.51	0.00	0.00	0.00		
KHE	0.22	0.22	0.22	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.00	0.00					
KID	0.59	0.59	0.59	0.84	0.84	0.84	0.84	0.84	0.00	0.00	0.00	0.00	0.00				
KNO	0.32	0.32	0.32	0.32	1.18	1.18	1.18	1.18	0.00	0.00	0.00						
LYE	0.39	0.39	0.39	1.37	1.37	1.37	1.37	1.37	1.37	1.37	0.81	0.81	0.81				
MAR	0.45	0.45	0.45	0.45	0.74												
PPA	0.57	0.57	0.57	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.02	0.02					
PRE	0.02	0.02	0.02	0.02	0.02	0.02	1.19	1.19	1.19	0.12	0.12	0.12	0.12				
SAN	0.35	0.35	0.35	1.78	1.78	1.78	1.78	1.78	1.78	1.78							
SCO	0.43	0.43	0.43	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.78	0.78	0.78				
SCR	0.29	0.29	0.29	0.29	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.00	0.00				
SHI	0.32	0.32	0.32	0.32	0.89	0.89	0.89	0.89	0.89	0.89							
SOA	0.31	0.31	0.31	0.31	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.00	0.00	0.00	0.00	0.00	0.00
STO	0.29	0.29	0.29	0.29	0.91	0.91	0.91	0.91	0.23	0.23	0.23	0.23					
TIP	1.33	1.33	1.33	1.33	1.33	1.33	0.61	0.61	0.61	0.61	0.00						
WAL	0.32	0.32	0.32	1.26	1.26	1.26	1.26	1.26	1.26	0.34	0.34						
WBR	0.37	0.37	0.37	0.37	1.93	1.93	1.93	1.93	1.93	1.93	1.56	1.56	1.56	1.56			
WIT	0.66	0.66	0.66	0.66	1.35	1.35	1.35	1.35	1.35	0.00	0.00	0000	0.00	0.00			
WOR	0.22	0.22	0.22	0.22	0.44	0.44	0.44	0.44	0.44	0.44	0.20						
YAR	0.35	0.35	0.35	1.06	1.06	1.06	1.06	1.06	1.06	1.06	0.00	0000	0.00				

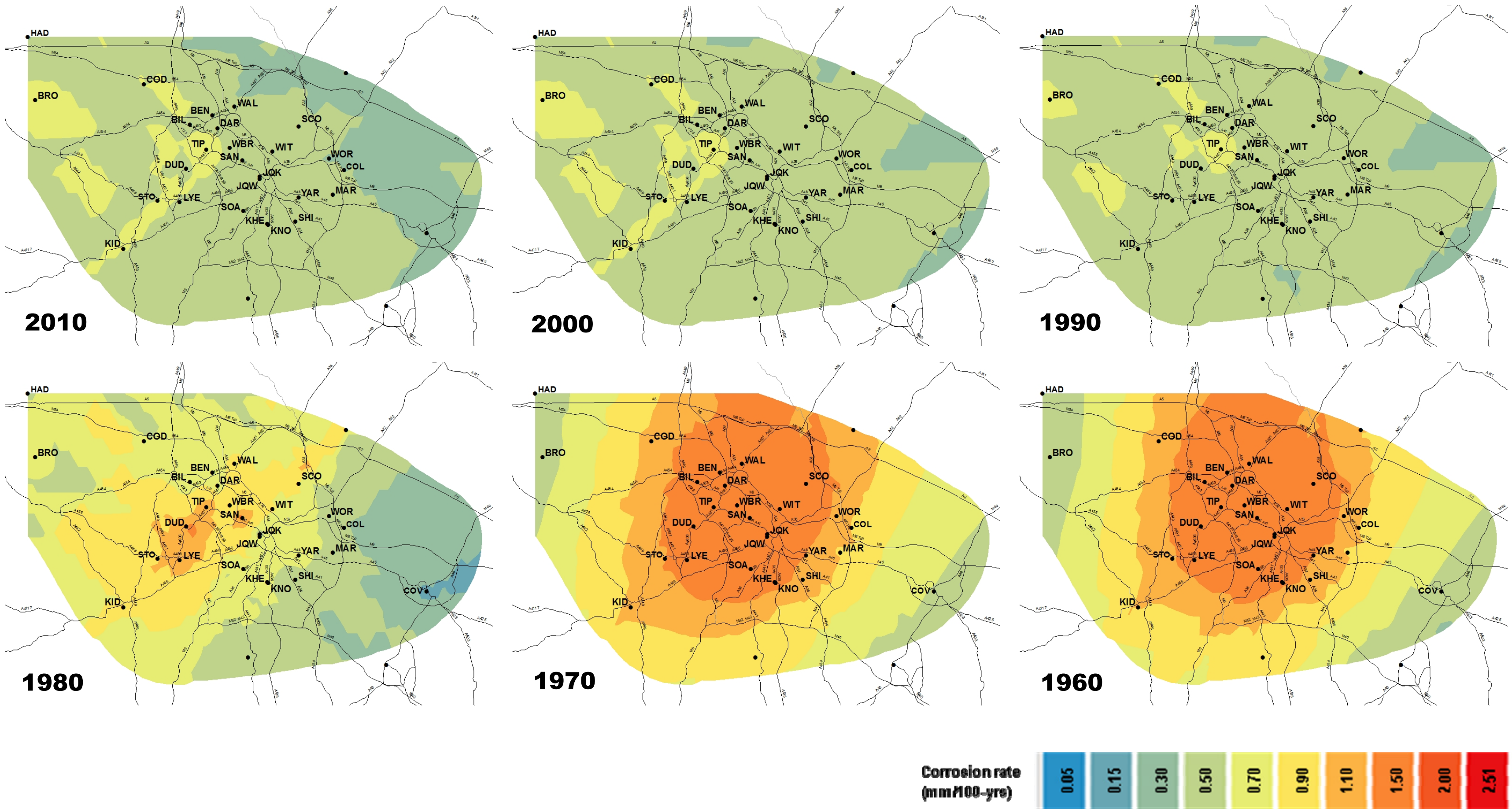

Figure 22. Spatial and temporal distribution of corrosion rates (mm/100-yrs) in ten year increments. Labeled cemeteries represent where data is present and used in kriging.

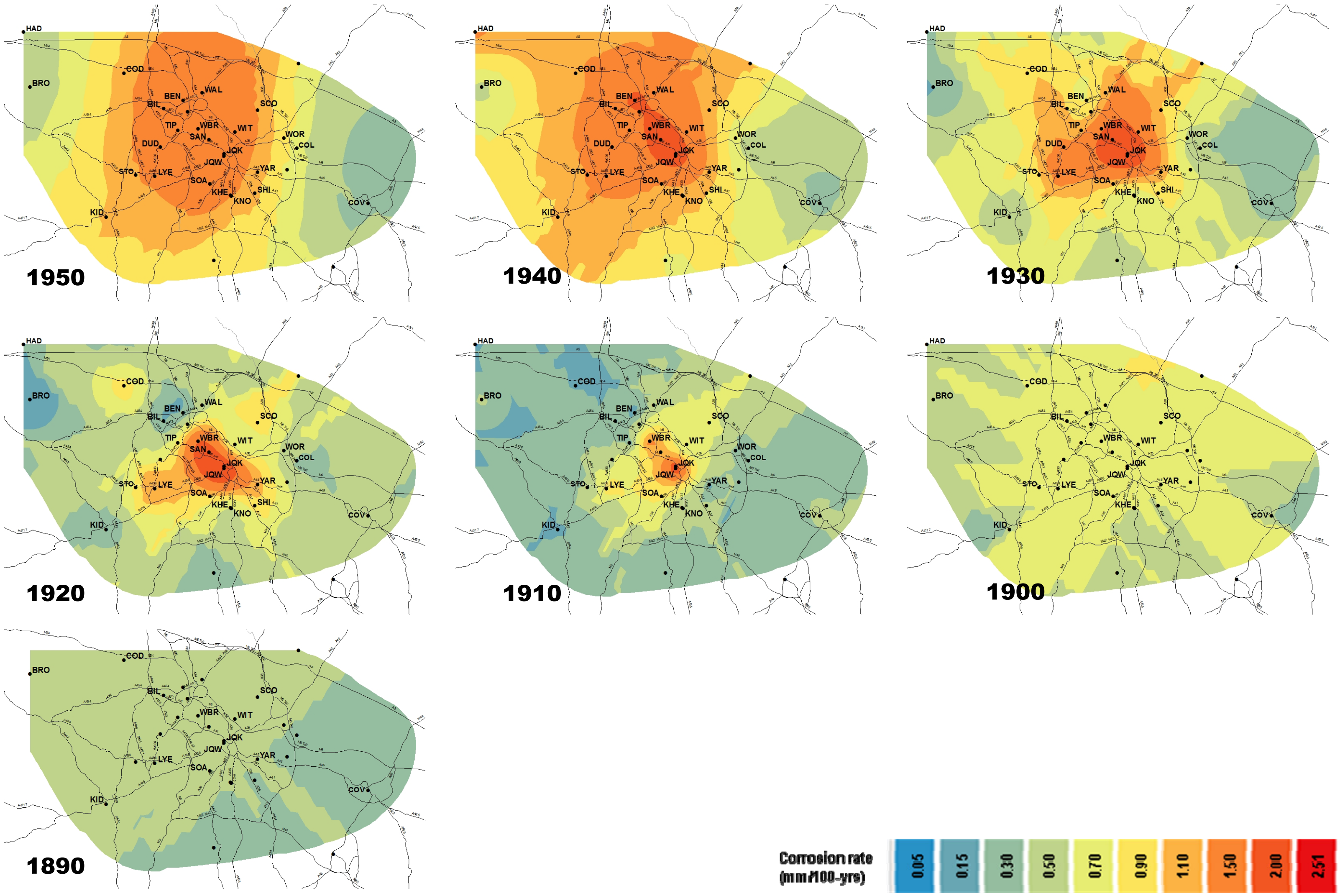

Figure 22. Continued.

Because PPA and PRE are geographically isolated from the concentration of cemeteries centered on Birmingham, PPA and PRE are shown separately (Figure 23). The corrosion values at PPA and PRE are considered to be background values as neither cemetery experiences a sharp increase or decrease in corrosion rates (mm/100-yrs) from 1890 to 2010. The lowest corrosion rates for the two cemeteries occur in two parts, 1) from 1890-1920 and 2) from 1960 to 1980. Corrosion rates slightly increase from 1990 to 2010 for both cemeteries.

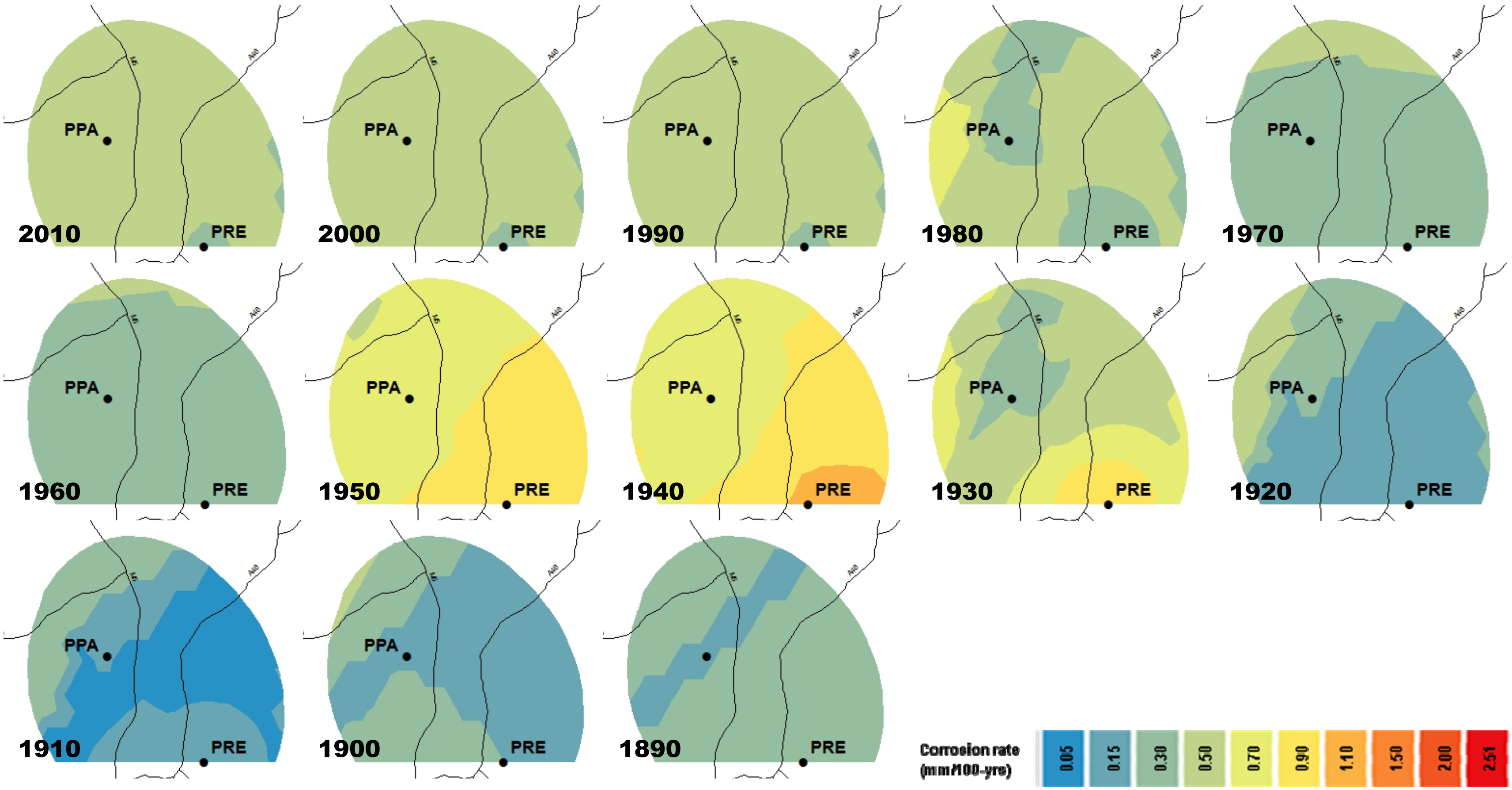

Figure 23. Spatial and temporal distribution of corrosion rates (mm/100-yrs) for PPA and PRE.

5. Discussion

The degree of gravestone corrosion by acid deposition correlates statistically with a number of physical and environmental variables. These variables include tree cover, gravestone texture, local elevation differences, geographic location, age of inscription, and gravestone variability.

Cooke et al. (1995) suggest that tree cover or overhanging structures could decrease the rate of marble gravestone corrosion. Because tree cover shelters gravestones, the presence of an overhanging canopy would effectively decrease the amount of acid deposition. Acid deposition is greater in areas where there are no overhanging obstructions. This relationship can be seen in JQK/JQW, where gravestone corrosion rates are reduced by approximately 20 percent under the tree cover at JQK. SOA and YAR also reflect this relationship as gravestone corrosion rates under tree cover decreased approximately by ten percent and 40 percent, respectively, from gravestones not under tree cover at these cemeteries. The percentage decrease in gravestone corrosion rates from tree cover is likely influenced by the proximity of the cemetery to the source of emissions.

Mooers (personal communication, 2010; unpublished data) suggested that acid fog may contribute to greater gravestone corrosion than acid rain because of its lingering effect and also that it could be attributed to local elevation differences within a single cemetery. Field observations from the 2005-2008 field studies (H. D. Mooers, personal communication, 2010) and the 2010 field study indicated fog did not occur more frequently in topographic lows relative to highs. However, no long-term observations were made nor were any references to the occurrence of fog and increased gravestone corrosion rates found. Statistical analysis of data collected for this study revealed high corrosion rates at higher elevations within cemeteries (Figure 14, Figure 15). This relationship may be a reflection of a greater density of trees at lower elevation; denser tree cover would shelter gravestones thereby reducing corrosion rates. Initial studies of the effects of cemetery variables on gravestone corrosion rates suggest this relationship may be more complicated that initially hypothesized.

The industrial and/or residential growth of the Black Country and surrounding communities was made possible by the close proximity of readily available natural resources of the Black Country such as coal, sandstone, and limestone (Allen, 1966). These resources were transported through a network of canals, railways, and roads to the surrounding communities, and they eventually led to a substantial increase in industrial and/or residential development. Consumption of raw materials correlates with this growth in industrial and/or residential development (Black Country Living Museum, 20 June 2010). The spatial pattern of corrosion rates in the West Midlands can be directly correlated to changes in population densities. As populations grew, people migrated to major industrial and/or residential centers, changing the spatial pattern of acid deposition from widely-spaced to clustered point sources (Figure 22).

As seen in Figure 22, cemetery corrosion rates varied regionally across the West Midlands. The 2010 dataset and 2005-2008 dataset (H. D. Mooers, unpublished data) show that areas highly affected by pollution from industrial and/or residential growth were centered on the Black Country and the City of Birmingham (Figure 22). For example, the historical development of the industrial and residential community surrounding SOA and JQK/JQW correlates well to the cemetery corrosion rates. Corrosion rates increase dramatically during the 1920s in the period of residential expansion after WWI. Populations in the Birmingham city center grew by 65 percent from 1861 to 1911 (Birmingham City Council, 2010a) (Figure 24).

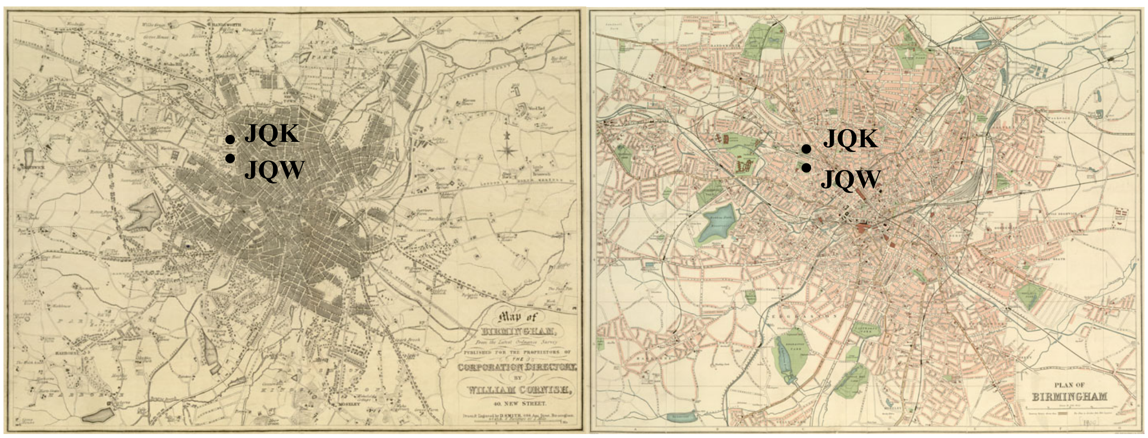

Figure 24. Maps show significant industrial and residential expansion of the Birmingham city center from 1864 (left) and 1909 (right). Points represent present locations of JQK and JQW cemeteries. Maps modified from the Birmingham City Council (2010b).

From 1910 and 1920, industrial and/or residential activity was centered on JQK/JQW in the Birmingham City center and on WBR in the Black Country. Industrial and/or residential growth gradually increased around these centers and clustered into one major 'hot spot' by 1950 (Figure 22). Acid deposition rates remained fairly constant into the 1970s. Between 1970 and 1980 it is evident that acid deposition rates drastically decreased. This decrease is attributed to the efficacy of the air pollution control measures that were implemented throughout the 1970s in response to implementation of the environmental control legislation (Albin, 1995). Acid deposition rates remained generally low from 1980 to 2010 with the exception of the Black Country cemeteries and rural cemeteries. Industrial areas of the Black Country and farther west to Brosley exhibited higher than average corrosion rates after 1990.

Reddy and Doe (2000) discuss the effects of precipitation rates on rainfall acidity; low precipitation rates often have pH < 4, whereas high precipitation rates can result in a rainfall pH greater than 4.5. Historic meteorological data would assist in a greater understanding of the effects of light to heavy rainfall events on marble dissolution. This effect has not been addressed in this study and therefore, gravestone corrosion rates presented in this study represent a minimum acid deposition rate recorded for the West Midlands.

Rural cemeteries, such as PPA and PRE, show no significant change in corrosion rates from 1890 to 2010 (Figure 23) unlike that seen in Figure 22. PPA and PRE very likely represent background corrosion rates, relatively unaffected by industrial and/or large-scale residential development. The slight increase in PPA and PRE corrosion rates after 1980 likely reflects population growth. BRO also experienced an increase in corrosion rates after 1980; again this likely represents an increase in population and/or industrial activity in the area.

Klein et al. (2004) indicate a decrease in sulfur oxide (SO_x) and NO_x emissions, in addition to sulfur (S) and nitrogen (N) deposition from 1980 to 2002 (Table 10) in the United Kingdom. This decrease in emissions and deposition is also a direct result of the environmental clean-up efforts. Following initial control measures to reduce SO_2 emission, controls were extended to NO_x in efforts to broaden the control of acidification throughout England (Fowler et al., 2007,) as well as worldwide (Bricker and Rice, 1993).

However, the decrease of sulfur deposition seen as a result of these measures was dependent on the proximity of the location to an industrial or residential source. Corrosion rates calculated from this investigation for pre-and post-environmental clean-up are shown in Table 11. Averages from the 2010 dataset and 2005-2008 dataset (H. D. Mooers, unpublished data) indicate the rate of corrosion following environmental clean-up to be 0.54 mm/100-yrs and 0.78 mm/100-yrs before environmental clean-up measures were implemented. This decrease in corrosion rates from pre- to post-environmental clean-up indicates the efficacy of the clean-up efforts of the 1970s.

Table 10. Emissions and deposition decrease from 1980 to 2002 in the UK (Klein et al., 2004).

	Percent decrease from 1980 to 2002
SO_x emissions	79 %
NO_x emissions	39 %
S deposition	72 %
N deposition	16 %

Table 11. Pre- and post-environmental clean-up cemetery corrosion rates.

Cemetery ID	Inscription Range	Pre-environmental clean-up (≤ 1970) (mm/100-yrs)	Post-environmental clean-up (2010-1970) (mm/100-yrs)	Percent decrease in corrosion rate
BEN	1971-1905	1.19	0.44	63.03
BIL	1981-1864	0.59	0.61	(3.39 increase)
BRO	1996-1887	0.16	0.52	(225.00 increase)
COD	2006-1882	0.67	0.61	8.96
COL	2004-1905	0.56	0.57	(1.79 increase)
COV	1945-1870	0.22	0.00	100.00
DAR	2009-1951	0.69	0.48	30.43
DUD	2006-1922	1.36	0.72	47.06
HAD	1991-1896	0.27	0.25	7.41
JQK	1990-1857	1.38	0.44	68.12
JQW	1992-1867	1.82	0.80	56.04
KHE	1980-1899	0.54	0.42	22.22
KID	1972-1883	0.37	0.69	(86.49 increase)
KNO	2002-1908	0.67	0.49	26.87
LYE	1963-1881	1.19	0.78	34.45
MAR	2004-1962	0.74	0.51	31.08
PPA	1945-1891	0.14	0.41	(192.86 increase)
PRE	1942-1889	0.45	0.02	95.56
SAN	2009-1912	1.78	0.93	47.75
SCO	1969-1888	0.90	0.64	28.89
SCR	1998-1889	0.41	0.33	19.51
SHI	2006-1916	0.89	0.43	51.69
SOA	2005-1850	0.46	0.42	8.70
STO	2002-1892	0.57	0.41	28.07
TIP	1989-1909	0.72	1.33	(84.72 increase)
WAL	2007-1902	0.99	0.69	30.30
WBR	2008-1872	1.78	0.68	61.80
WIT	1998-1880	0.67	0.79	(17.91 increase)
WOR	1984-1909	0.40	0.26	35.00
YAR	2008-1885	0.71	0.63	11.27

5.1 Conversion of Acid Deposition to Atmospheric Concentration

Converting the modern gravestone corrosion rates into atmospheric deposition rates provides a framework for reference (Figure 25). Because sulfuric acid (H_2SO_4) and marble ($CaCO_3$) are 1:1, one sulfur atom yields one molecule of sulfuric acid which destroys one molecule of $CaCO_3$. Acid deposition rates of the West Midlands collected in this study also correlate well with the acid deposition conversion from lake acidification measurements made by Battarbee and Renberg (1990). The average corrosion rate for all cemeteries from the 2010 dataset and 2005-2008 dataset (H. D. Mooers, unpublished data) averaged 0.64 mm/100yrs. This converts to 5.17 $gm^{-2}a^{-1}$ S deposition which falls within the 4 $gm^{-2}a^{-1}$ S deposition isobar, encompassing the West Midlands, calculated by Battarbee and Renberg (1990).

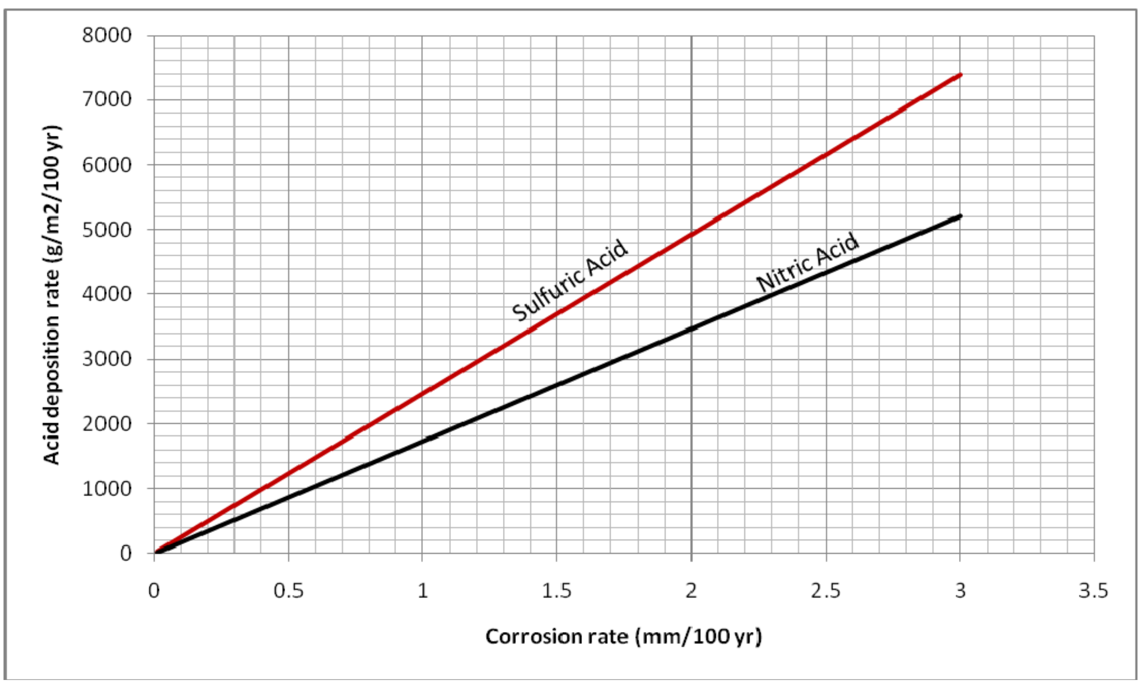

Figure 25. Conversion of corrosion rates (mm/100-yrs) to acid deposition rates (g/m^2/100-yrs).

Data collected by the Automatic Urban and Rural Monitoring Network (AURN), UK for the Birmingham city center are shown in Table 12. AURN SO_2 atmospheric concentration data were averaged and used to calculate the residence time of SO_2 for the city center of Birmingham. Recent cemetery corrosion rates calculated for JQK and JQW from 2000 to 2010 were averaged and used as sink rates in this calculation (Table 13).

Table 12. AURN atmospheric SO_2 concentrations.

AURN Birmingham city center SO_2 atmospheric concentrations	
Date	**μgm^{-3} SO_2**
1/1/2005 - 12/31/2005	2.457
1/1/2006 - 12/31/2006	2.286
1/1/2007 - 12/31/2007	2.367
1/1/2008 - 12/31/2008	1.696
1/1/2009 - 12/31/2009	2.112
1/1/2010 - 12/31/2010	1.535
Average	*2.076*

Table 13. Birmingham city center 2000-2010 cemetery SO_2 acid deposition rates.

Recent cemetery data collected (2000-2010)	**$gm^{-2}a^{-1}$ SO_2**
JQK	1.80
JQW	6.05
Average	*3.93*

Using the steady-state box model, the acid deposition rates and modern concentrations can be used to determine the residence time (τ) of SO_2 in the atmosphere if the height of the air column (V) is know. For an air column height of 500m, $\tau = 0.1$ days, and for an air column height of 5000m, $\tau = 1$ day. This range of SO_2 residence time and air column height can be used to convert past acid deposition rates to atmospheric concentrations of SO_2. Acid deposition rates for JQK/JQW cemeteries averaged 35.10 $gm^{-2}a^{-1}$ SO_2 from 1900-1970. The calculated atmospheric concentration of SO_2 from 1900-1970 for the Birmingham city center was 18.5 μgm^{-3} SO_2.

After removing the effects of tree cover and texture on corrosion, a considerable amount of variability still exists in the 2010 dataset and 2005-2008 dataset (H. D. Mooers, unpublished data). The remaining variability in these datasets could be explained either by variables not collected in this study or gravestone variability. Gravestone variability is the largest source of unadjusted variability seen in the 2010 dataset and 2005-2008 dataset (H. D. Mooers, unpublished data). Cooke et al. (1995) also reports increasing variability and data scatter with older inscriptions. Characteristics of marble such as geological setting, metamorphic processes, stone porosity, crystal size, and orientation of crystals contribute to stone variability (Garzonio and Cantisani, 2006). This study was unable to address the internal effects of marble variability. Further petrographic and chemical analysis could assess the effects of gravestone variability on corrosion measurements.

The clustering effect of high gravestone corrosion rates around active industrial and/or residential centers in the West Midlands for the past 160 years corresponds to the residency time of SO_2 in the atmosphere. The reported residence time of SO_2 in a polluted atmosphere ranges from one to five days (Hidy, 1994; Katz, 1977). Dependent on meteorological conditions present during sulfur emission (e.g. wind direction and speed, humidity, and temperature), residence time in the atmosphere is variable (Weber, 1970). However, given the nature of sulfur emissions prior to and after enactment of environmental legislation, there has likely been an associated change in atmospheric residence time; the finer the particulates the slower the atmospheric fall rate and greater the residence time. It is reasonable that prior to 1970 or so, the unregulated emissions were characterized by much larger particulates. The fallout rate would be much more rapid and the atmospheric residence time far shorter. The aforementioned clustering effect of high gravestone corrosion rates near industrial and/or residential centers indicates a high correlation of residency times with source emissions, thus indicating residency time of SO_2 in the lower atmosphere was likely short, possibly much less than one day. If pollutants and particulates remain in the atmosphere for at least one day, the spatial clustering ceases. Therefore, the residency time of SO_2 during high industrialization and residential expansion was less than one day.

6. Conclusions

Monument corrosion is an excellent measure of the spatial and temporal sensitivity to acid deposition. Further assessment of physical and environmental variables of the West Midlands yielded a greater understanding as to the effects of these variables on monument corrosion rates and how one might make adjustments. This study focused on the statistical analysis of variables including tree cover, gravestone texture, local elevation differences, geographic location, age of inscription, and gravestone variability.

Identifying the relationships between variables and gravestone corrosion rates both aids in better selection criteria for gathering future data and in the correction for variables. Statistical analysis of variables and gravestone corrosion rates indicate that tree cover, local elevation differences, gravestone texture, and algae/lichen cover were statistically significant (p-value ≤ 0.5). Variables with limited information were not chosen to make data adjustments. While some relationships between variables and corrosion rates remain unclear, tree cover and texture were selected for data adjustment. After tree effects and texture effects were adjusted, considerable variability remains in the datasets. Gravestone variability likely accounts for the remaining variability seen in the datasets.

Data illustrate a clustering effect of high gravestone corrosion rates surrounding areas of high industrial and/or residential expansion. This highly correlated clustering indicates at time of high industrial and/or residential activity, the residency time of SO_2 in the atmosphere to be less than one day. Calculations indicate that if residency time was at one day the spatial patterns would drastically fade. SO_2 residency times of less than one day correlate to the qualitative assessments of the ambient air conditions during heavy industrialization. The inefficient burning at this time produced massive amounts of corrosive pollutants and large particulates which settled out of the air column within close proximity to the source.

The conversion of cemetery corrosion rates to SO_2 atmospheric concentration indicates a strong correlation with recent AURN atmospheric monitoring network and lake studies (Battarbee and Renberg, 1990). Because external atmospheric concentration data is limited within the study area, correlations represent general trends. By using the steady-state box model to calculate SO_2 residence time and atmospheric concentration, we showed that SO_2 atmospheric concentration significantly decreased after the implementation of environmental clean-up legislation. This study has shown that by using lead-lettered marble gravestone corrosion as a proxy for acid deposition we are able to assess the effect of the industrialization of the West Midlands on acid deposition in the region. The 2010 dataset and 2005-2008 dataset show great spatial and temporal coverage of acid deposition within the West Midlands. These results not only illustrate the efficacy of 1970s environmental control legislation but also address proximity to source emissions.

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APPENDIX A

Cemetery Information

2010 Dataset

Cemetery ID	Cemetery name	UTM coordinate	Neighborhood
BIL	Bilston Cemetery	30 U 561866 5825044	Bilston
COD	Saint Nicholas Churchyard	30 U 554119 5831975	Codsall
COL	Coleshill Parish Church/Cemetery	30 U 588007 5817313	Coleshill
DAR	Fallings Heath Cemetery	30 U 566570 5824432	Darlaston
JQK*	Key Hill Cemetery	30 U 573743 5816222	Jewellery Quarter
JQW*	Warstone Lane Cememtery	30 U 573730 5815781	Jewellery Quarter
MAR	Marston Green Burial Grounds	30 U 586086 5813062	Marston Green
SAN*	Handsworth Cemetery	30 U 570750 5818928	Sandwell
SHI*	Robin Hood Cemetery and Crematorium	30 U 579776 5808467	Shirley
SOA*	Lodge Hill Cemetery and Crematorium	30 U 570966 5810346	Selly Oak
WAL	Ryecroft Cemetery	30 U 569438 5828132	Walsall
WBR	Heath Lane Cemetery	30 U 568630 5821123	West Bromwich
WOR	Saint Peter and Saint Paul Parish Church	30 U 585444 5819309	Water Orton
YAR	South Yardley Cemetery and Crematorium	30 U 580324 5812585	South Yardley

* Also contains data from the 2005-2008 dataset (H.D. Mooers, unpublished data).

2005-2008 Dataset (H. D. Mooers, unpublished data)

Cemetery ID	Cemetery name	UTM coordinate	Neighborhood
BEN		30 U 565735 5826699	Bentley
BRO		30 U 535661 5829272	Brosely
COV	London Road Cemetery	30 U 602002 5806541	Coventry
DUD	Scot's Green Cemetery	30 U 561285 5817504	Dudley
HAD		30 U 534457 5840038	Hadley
KHE	Brandwood End Cemetery	30 U 574978 5808054	Kings Heath
KID		30 U 550592 5803814	Kidderminster
KNO	Saint Nicholas Cemetery	30 U 575167 5807964	Kings Norton
LYE		30 U 560133 5811808	Lye
PPA		30 U 557747 5759740	Priors Park
PRE		30 U 565720 5751003	Prestbury
RED		30 U 571699 5795298	Redditch
SCO		30 U 580327 5824737	Sutton Coldfield
SCR	All Saints Church	30 U 632321 5833847	Scraptoft
STO	Stourbridge Crematorium	30 U 556494 5811652	Stourbridge
TAM		30 U 588327 5833869	Tamworth
TIP	Tipton Cemetery	30 U 564697 5820810	Tipton
WAR		30 U 595110 5794078	Warwick
WIT		30 U 575877 5820467	Witon

Gravestone Variable and Inscription Information

2010 Dataset

Gravestone variable: No tree present (N), tree cover (Y); high elevation within the cemetery (H), low elevation within the cemetery (L); white colored gravestone or no algae/lichen cover (W), light algae/lichen cover (F), moderate algae/lichen cover (M), heavy algae/lichen cover (D); roughly textured inscription surface (R), smoothly textured inscription surface (S); missing variable/not collected (. , U),

* Year taken from the date line/date of death for the inscription measured

** Trimmed mean for the ten measurements taken from the inscription date line

Cemetery ID	Stone	Inscription #	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Color	Texture
BIL	1	1	1902	0.71	N	250	U	M	S
		2	1932	0.74					
		3	1946	0.51					
BIL	2	1	1905	0.49	Y	90	U	M	S
		2	1924	0.47					
BIL	3	1	1898	0.88	N	85	U	M	S
		2	1899	0.88					
		3	1921	0.86					
		4	1955	0.38					
BIL	4	1	1898	1.12	N	85	U	F	S
		2	1915	1.22					
		3	1917	1.15					
BIL	5	1	1897	1.40	N	78	U	F	R
		2	1913	1.32					
BIL	6	1	1887	0.64	N	45	U	D	S
		2	1911	0.78					
		3	1912	0.83					
		4	1927	0.69					
BIL	7	1	1883	0.71	N	40	U	M	S
		2	1895	0.70					
		3	1919	0.58					
BIL	8	1	1864	0.73	N	20	U	D	R
		2	1906	0.80					
		3	1929	0.76					
BIL	9	1	1879	0.81	N	340	U	D	S
		2	1884	0.73					
BIL	10	1	1900	0.58	N	340	U	M	R
		2	1910	0.54					
		3	1924	0.48					

Cemetery ID	Stone	Inscription #	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Color	Texture
BIL	11	1	1921	1.40	N	325	U	M	S
		2	1941	0.89					
		3	1945	0.86					
		4	1981	0.20					
BIL	12	1	1916	0.80	N	300	U	M	S
		2	1954	0.47					
BIL	13	1	1919	1.02	N	280	U	M	R
		2	1922	1.13					
		3	1922	1.19					
		4	1930	1.08					
BIL	14	1	1923	0.72	N	290	U	M	R
		2	1933	0.74					
		3	1939	0.65					
BIL	15	1	1922	0.71	Y	185	U	M	R
		2	1925	0.76					
		3	1938	0.42					
BIL	16	1	1929	1.31	N	170	U	W	R
		2	1941	0.94					
		3	1955	0.93					
BIL	17	1	1929	0.81	N	70	U	M	S
		2	1966	0.14					
BIL	18	1	1934	0.73	N	75	U	M	S
		2	1956	0.55					
BIL	19	1	1929	0.56	N	72	U	D	S
		2		0.54					
BIL	20	1	1911	0.62	N	80	U	D	S
		2	1917	0.57					
		3	1927	0.57					
BIL	21	1	1925	0.72	N	80	U	D	S
		2	1937	0.66					
		3	1939	0.63					
BIL	22	1	1920	0.73	N	70	U	M	S
		2	1958	0.13					
BIL	23	1	1928	0.67	N	65	U	M	S
		2	1943	0.50					
BIL	24	1	1929	0.54	N	75	U	D	S

Cemetery ID	Stone	Inscription #	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Color	Texture
		2	1949	0.43					
		3	1951	0.44					
BIL	25	1	1924	0.64	N	75	U	D	S
		2	1932	0.65					
		3	1935	0.54					
		4	1953	0.25					
BIL	26	1	1927	0.98	N	55	U	F	S
		2	1933	0.81					
BIL	27	1	1928	0.85	N	50	U	M	S
		2		0.43					
BIL	28	1	1926	1.05	N	70	U	D	R
		2	1933	1.10					
BIL	29	1	1927	0.54	N	10	U	M	R
		2	1938	0.59					
BIL	30	1	1926	1.08	N	5	U	M	R
		2	1933	1.01					
BIL	31	1	1915	0.95	N	295	U	M	S
		2	1917	0.97					
BIL	32	1	1900	1.01	N	290	U	M	S
		2	1912	1.07					
BIL	33	1	1929	0.81	N	60	U	M	S
		2	1950	0.51					
BIL	34	1	1931	0.87	N	75	U	M	S
		2	1933	0.87					
		3	1947	0.56					
BIL	35	1	1930	0.81	N	65	U	M	S
		2	1935	0.81					
		3	1954	0.33					
BIL	36	1	1913	1.01	N	330	U	D	R
		2	1940	0.85					
		3	1943	0.66					
BIL	37	1	1933	0.99	N	330	U	M	S
		2	1942	0.99					
BIL	38	1	1934	0.74	N	300	U	D	S
		2	1937	0.81					
BIL	39	1	1897	1.39	N	290	U	W	S

Cemetery ID	Stone	Inscription #	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Color	Texture
		2	1915	1.34					
		3	1937	0.90					
		4	1940	0.87					
BIL	40	1	1933	0.99	N	300	U	M	S
		2	1951	0.69					
BIL	41	1	1933	0.75	N	300	U	D	S
		2	1946	0.63					
		3	1946	0.59					
BIL	42	1	1928	0.67	N	300	U	D	R
		2	1949	0.72					
BIL	43	1	1922	0.64	Y	290	U	D	S
		2	1938	0.63					
BIL	44	1	1911	0.36	N	295	U	D	S
		2	1920	0.41					
		3	1956	0.29					
BIL	45	1	1931	1.07	N	60	U	W	R
		2	1926	1.09					
		3	1950	0.95					
BIL	46	1	1914	0.92	N	75	U	U	S
		2	1918	1.07					
		3	1931	1.12					
BIL	47	1	1934	0.58	N	75	U	D	S
		2	1968	0.16					
COD	1	1	1976	0.13	N	120	U	U	S
		2	.	0.09					
COD	3	1	1964	0.14	N	120	U	U	S
		2	1972	0.14					
COD	4	1	1957	0.55	N	120	U	U	S
		2	1965	0.49					
COD	5	1	1937	1.11	N	120	U	W	S
		2	1979	0.33					
		3	2006	0.06					
COD	6	1	1920	0.86	N	120	U	U	S
		2	1932	0.69					
COD	7	1	1882	0.70	N	120	U	M	S
		2	1927	0.56					

Cemetery ID	Stone	Inscription #	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Color	Texture
COD	8	1	1887	0.69	N	120	U	M	S
		2	1891	0.69					
		3	1906	0.68					
COL	1	1	1907	0.53	N	60	U	M	S
		2	1927	0.54					
COL	2	1	1905	0.66	N	60	U	M	R
		2	1914	0.55					
		3	1926	0.52					
COL	3	1	1907	0.86	N	60	U	M	R
		2	1923	0.74					
COL	4	1	1914	0.39	N	60	U	M	S
		2	1937	0.33					
		3	1945	0.27					
COL	5	1	1907	0.49	N	60	U	M	S
		2	1918	0.36					
COL	6	1	1909	0.25	N	60	U	M	S
		2	1911	0.28					
COL	7	1	1912	0.95	N	60	U	W	S
		2	1918	0.92					
		3	1930	0.84					
		4	1949	0.80					
COL	8	1	1937	0.69	N	60	U	M	S
		2	1976	0.12					
COL	9	1	1937	0.62	N	60	U	M	S
		2	1954	0.36					
COL	10	1	1932	0.51	N	60	U	M	S
		2	1946	0.41					
		3	1992	0.07					
COL	11	1	1931	0.53	N	60	U	F	S
		2	1938	0.53					
		3	1986	0.12					
COL	12	1	1956	0.58	N	60	U	M	S
		2	1969	0.28					
		3	1993	0.04					
COL	13	1	1965	0.16	N	60	U	M	S
		2	1968	0.16					

Cemetery ID	Stone	Inscription #	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Color	Texture
COL	14	1	1965	0.28	N	60	U	M	S
		2	1991	0.06					
COL	15	1	1975	0.12	N	60	U	M	S
		2	1981	0.08					
COL	16	1	1974	0.05	N	60	U	M	S
		2	1978	0.04					
COL	17	1	1972	0.26	N	60	U	W	S
		2	1984	0.08					
COL	18	1	1970	0.22	N	60	U	W	S
		2	2001	0.02					
COL	19	1	1969	0.14	N	60	U	W	S
		2	2003	0.00					
COL	20	1	1970	0.17	N	60	U	W	S
		2	2004	0.00					
DAR	1	1	1982	0.18	N	80	U	W	S
		2	1998	0.06					
		3	2005	0.02					
DAR	2	1	1982	0.02	N	80	U	M	S
		2	1992	0.01					
DAR	3	1	1982	0.04	N	80	U	M	S
		2	1986	0.02					
DAR	4	1	1951	0.14	N	80	U	W	S
		2	1982	0.09					
DAR	5	1	1952	0.26	N	80	U	U	S
		2	1955	0.24					
		3	1989	0.20					
		4	1989	0.15					
		5	2009	0.03					
DAR	6	1	1953	0.07	N	80	U	D	S
		2	1977	0.05					
DAR	7	1	1953	1.12	N	80	U	W	R
		2	1966	0.65					
		3	1999	0.27					
DAR	8	1	1981	0.07	N	80	U	W	S
		2	1982	0.04					
DAR	9	1	1954	0.47	N	80	U	W	S

Cemetery ID	Stone	Inscription #	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Color	Texture
		2	1985	0.08					
DAR	10	1	1954	0.35	N	80	U	D	S
		2	1957	0.31					
		3	1973	0.06					
DAR	11	1	1981	0.10	N	80	U	W	S
		2	1982	0.05					
DAR	12	1	1964	0.29	N	80	U	F	S
		2	1993	0.04					
DAR	13	1	1960	0.72	N	80	U	W	S
		2	1990	0.40					
		3	2008	0.01					
DAR	14	1	1953	0.52	N	80	U	D	S
		2	1971	0.13					
DAR	15	1	1955	0.50	N	80	U	W	R
		2	2006	0.03					
DAR	16	1	1958	0.55	N	80	U	W	S
		2	1964	0.37					
		3	2002	0.00					
DAR	17	1	1961	0.44	N	80	U	W	S
		2	1964	0.41					
		3	2006	0.03					
DAR	18	1	1968	0.46	N	260	U	W	S
		2	2003	0.09					
JQK	6	1	1866	1.88	Y	0	H	D	S
		2	1892	1.96					
		3	1896	1.84					
		4	1905	1.69					
JQK	7	1	1866	2.48	Y	340	H	M	S
		2	1875	2.21					
		3	1882	1.68					
JQK	8	1	1880	0.91	Y	330	L	M	S
		2	1892	0.91					
		3	1923	0.62					
JQK	9	1	1876	1.69	Y	330	L	D	S
		2	1877	1.46					
JQK	10	1	1875	1.87	Y	110	L	D	S

Cemetery ID	Stone	Inscription #	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Color	Texture
		2	1883	1.93					
		3	1897	1.99					
		4	1914	1.48					
		5	1916	1.56					
JQK	11	1	1883	1.11	Y	305	L	D	S
		2	1909	0.86					
		3	1915	0.82					
JQK	12	1	1878	1.00	Y	300	L	D	S
		2	1886	1.05					
		3	1909	0.81					
JQK	13	1	1939	0.63	Y	195	L	M	S
		2	1947	0.52					
JQK	14	1	1890	0.75	Y	300	L	U	S
		2	1908	0.46					
		3	1912	0.43					
JQK	15	1	1873	1.37	Y	300	L	M	S
		2	1874	1.32					
		3	1900	1.29					
		4	1909	1.06					
JQK	16	1	1887	1.29	U	300	L	M	R
		2	1903	1.37					
		3	1907	1.44					
		4	1928	1.15					
JQK	17	1	1857	1.96	Y	120	L	M	R
		2	1859	1.97					
		3	1905	1.41					
JQK	18	1	1870	2.35	U	300	L	M	R
		2	1872	2.32					
		3	1899	2.30					
		4	1909	1.67					
		5	1933	1.08					
JQK	19	1	1875	1.66	U	300	L	M	R
		2	1887	1.71					
		3	1895	2.03					
		4	1904	1.72					
JQK	20	1	1865	0.87	U	300	L	M	S

Cemetery ID	Stone	Inscription #	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Color	Texture
		2	1883	1.02					
		3	1898	1.14					
		4	1913	0.87					
		5	1956	0.25					
JQK	21	1	1951	0.32	Y	300	L	D	S
		2	1968	0.18					
JQK	22	1	1892	1.95	Y	300	L	D	S
		2	1895	1.62					
JQK	23	1	1880	2.18	Y	300	L	D	R
		2	1898	1.98					
		3	1902	1.94					
JQK	24	1	1886	0.77	Y	110	L	D	S
		2	1906	0.67					
		3	1934	0.63					
		4	1943	0.63					
		5	1947	0.40					
JQK	25	1	1952	0.36	Y	115	L	M	S
		2	1974	0.07					
JQK	26	1	1949	0.32	Y	115	L	D	S
		2	1951	0.35					
JQW	11	1	1935	0.61	N	90	H	D	S
		2	1961	0.23					
JQW	12	1	1939	1.09	Y	90	H	W	S
		2	1951	0.69					
		3	1963	0.36					
JQW	13	1	1926	1.38	N	90	H	D	R
		2	1939	1.02					
		3	1941	0.75					
JQW	14	1	1927	1.43	N	90	H	D	S
		2	1964	0.56					
		3	1967	0.43					
JQW	15	1	1879	2.65	N	90	H	W	S
		2	1900	2.18					
JQW	16	1	1933	0.95	N	90	H	M	S
		2	1944	0.76					
JQW	17	1	1933	1.15	N	90	H	M	S

Cemetery ID	Stone	Inscription #	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Color	Texture
		2	1953	0.78					
		3	1966	0.35					
JQW	18	1	1949	1.07	N	90	H	M	S
		2	1992	0.09					
JQW	19	1	1892	1.79	N	90	L	F	S
		2	1901	1.91					
		3	1922	1.61					
		4	1940	0.94					
JQW	20	1	1908	1.47	N	90	L	M	R
		2	1920	1.35					
		3	1938	1.05					
JQW	21	1	1946	0.95	N	310	L	W	S
		2	1977	0.09					
		3	1983	0.02					
JQW	22	1	1883	1.72	N	90	H	M	S
		2	1900	1.57					
JQW	23	1	1893	2.92	Y	90	H	M	R
		2	1896	2.84					
		3	1899	2.01					
		4	1915	1.44					
JQW	24	1	1882	1.90	N	310	H	M	S
		2	1888	1.90					
		3	1892	1.74					
		4	1905	1.71					
		5	1908	1.62					
JQW	25	1	1902	1.48	N	90	H	D	S
		2	1927	1.56					
		3	1930	1.42					
JQW	26	1	1916	2.27	N	310	H	M	S
		2	1921	2.28					
		3	1937	1.79					
JQW	27	1	1883	2.01	Y	310	H	W	S
		2	1894	1.95					
		3	1903	1.75					
		4	1919	1.29					
JQW	28	1	1918	1.42	N	310	H	M	S

Cemetery ID	Stone	Inscription #	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Color	Texture
		2	1932	1.30					
JQW	29	1	1895	2.01	N	90	H	D	S
		2	1917	1.23					
JQW	30	1	1954	0.47	N	90	H	D	R
		2	1955	0.50					
MAR	1	1	1970	0.20	N	100	U	M	S
		2	1995	0.06					
MAR	2	1	1963	0.24	N	100	U	M	S
		2	1991	0.03					
MAR	3	1	1964	0.08	N	100	U	D	S
		2	1969	0.09					
MAR	4	1	1964	0.32	N	100	U	F	S
		2	1997	0.04					
MAR	5	1	1964	0.08	N	100	U	D	S
		2	1981	0.08					
MAR	6	1	1963	0.24	N	100	U	W	S
		2	2000	0.03					
MAR	7	1	1962	0.31	N	100	U	F	S
		2	1978	0.15					
MAR	8	1	1970	0.33	N	100	U	F	S
		2	1980	0.20					
MAR	9	1	1963	0.32	N	100	U	D	S
		2	1991	0.19					
MAR	10	1	1966	0.30	N	100	U	W	S
		2	1993	0.04					
MAR	11	1	1966	0.13	N	100	U	M	S
		2	1973	0.20					
MAR	12	1	1969	0.23	N	100	U	W	S
		2	1987	0.16					
MAR	13	1	1968	0.15	N	100	U	M	S
		2	1976	0.10					
MAR	14	1	1968	0.14	N	100	U	D	S
		2	1977	0.10					
MAR	15	1	1965	0.41	N	100	U	W	S
		2	2000	0.07					
MAR	16	1	1965	0.30	N	100	U	M	S

Cemetery ID	Stone	Inscription #	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Color	Texture
		2	1979	0.15					
MAR	17	1	1976	0.23	N	100	U	F	S
		2	2004	0.06					
MAR	18	1	1979	0.16	N	100	U	W	S
		2	2002	0.04					
MAR	19	1	1980	0.13	N	100	U	D	S
		2	1990	0.10					
MAR	20	1	1972	0.24	N	100	U	W	S
		2	2004	0.01					
SAN	15	1	1913	1.75	N	120	L	F	S
		2	1917	1.69					
		3	1917	1.85					
		4	1920	1.86					
SAN	16	1	1912	1.23	N	120	L	D	S
		2	1939	0.82					
		3	1947	0.61					
SAN	17	1	1913	1.32	N	120	L	M	S
		2	1935	0.94					
		3	1937	0.86					
		4	1940	0.50					
SAN	18	1	1915	0.96	N	120	L	W	S
		2	1931	0.94					
		3	1937	0.78					
		4	1987	0.09					
SAN	19	1	1917	1.58	N	120	L	M	R
		2	1924	1.41					
		3	1927	1.38					
		4	1948	0.89					
SAN	20	1	1934	0.72	N	120	L	D	S
		2	1961	0.19					
SAN	21	1	1921	0.70	Y	120	L	M	S
		2	1925	0.51					
		3	1953	0.48					
		4	1974	0.15					
SAN	22	1	1917	0.81	N	120	L	D	S
		2	1936	0.71					

Cemetery ID	Stone	Inscription #	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Color	Texture
SAN	23	1	1912	1.17	N	120	L	D	S
		2	1926	1.12					
		3	1931	0.96					
SAN	24	1	1917	1.12	N	120	L	D	S
		2	1950	0.72					
SAN	25	1	1913	1.05	N	120	L	D	S
		2	1931	0.51					
SAN	26	1	1949	0.48	N	120	L	D	S
		2	1973	0.17					
SAN	27	1	1924	1.03	N	120	L	D	S
		2	1940	0.66					
SAN	28	1	1924	1.07	N	120	L	M	S
		2	1940	0.68					
		3	1947	0.65					
		4	1966	0.22					
SAN	29	1	1921	0.67	N	120	L	D	S
		2	1947	0.31					
SAN	30	1	1967	0.52	N	300		D	S
		2	1990	0.09					
SAN	31	1	1945	0.60	N	120	L	M	S
		2	1971	0.23					
		3	1984	0.07					
SAN	32	1	1938	0.61	N	120	L	D	S
		2	1948	0.49					
		3	1973	0.08					
SAN	33	1	1946	0.81	Y	120	L	W	S
		2	1947	0.85					
		3	1999	0.11					
SAN	34	1	1966	0.29	N	120	L	W	S
		2	1998	0.04					
SAN	35	1	1977	0.40	N	300	H	W	S
		2	2000	0.12					
SAN	36	1	1976	0.39	N	280	H	W	S
		2	1977	0.33					
		3	1980	0.29					
SAN	37	1	1978	0.36	N	300	H	W	S

Cemetery ID	Stone	Inscription #	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Color	Texture
		2	1994	0.06					
SAN	38	1	1977	0.43	N	300	H	W	S
		2	1999	0.01					
SAN	39	1	1977	0.26	N	280	H	W	S
		2	2009	0.00					
SAN	40	1	1936	1.05	N	300	H	D	S
		2	1966	0.22					
		3	1977	0.08					
SAN	41	1	1931	1.01	N	150	H	M	R
		2	1940	0.96					
SAN	42	1	1930	0.98	N	120	H	D	S
		2	1933	1.07					
		3	1945	0.81					
SAN	43	1	1928	0.99	N	120	H	D	S
		2	1931	0.93					
SAN	44	1	1927	2.01	N	120	H	M	S
		2	1965	0.83					
		3	1979	0.26					
SAN	45	1	1930	0.48	N	120	H	M	S
		2	1954	0.55					
SAN	46	1	1931	1.22	N	120	H	M	S
		2	1931	1.28					
		3	1932	1.17					
SAN	47	1	1932	1.58	N	120	H	W	S
		2	1942	1.36					
SAN	48	1	1946	0.76	N	120	H	F	S
		2	1956	0.58					
		3	1976	0.11					
SAN	49	1	1958	0.56	N	300	H	M	S
		2	1978	0.09					
SAN	50	1	1927	1.06	N	270	H	M	R
		2	1935	1.04					
		3	1955	0.46					
SAN	51	1	1915	1.61	N	300	H	M	R
		2	1932	1.54					
		3	1935	1.74					

Cemetery ID	Stone	Inscription #	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Color	Texture
SAN	52	1	1918	1.26	N	300	H	M	S
		2	1933	1.28					
		3	1937	0.96					
SAN	53	1	1936	0.80	N	300	H	D	S
		2	1948	0.67					
SAN	54	1	1939	0.81	N	300	H	D	S
		2	1964	0.28					
SHI	7	1	1928	0.32	Y	80	U	M	S
		2	1963	0.06					
SHI	8	1	1940	0.35	N	80	U	M	S
		2	1949	0.34					
SHI	9	1	1938	0.26	N	80	U	M	S
		2	1949	0.25					
SHI	10	1	1936	0.40	N	80	U	D	S
		2	1938	0.43					
		3	1947	0.30					
		4	1955	0.12					
SHI	11	1	1934	0.64	N	80	U	M	S
		2	1936	0.61					
SHI	12	1	1936	0.40	N	80	U	D	S
		2	1966	0.15					
SHI	13	1	1968	0.23	N	80	U	M	S
		2	1994	0.04					
SHI	14	1	1968	0.31	N	80	U	D	S
		2	1973	0.19					
		3	1977	0.11					
SHI	15	1	1968	0.18	N	80	U	M	S
		2	1995	0.06					
SHI	16	1	1947	0.62	N	80	U	D	S
		2	1952	0.58					
		3	1977	0.13					
SHI	17	1	1954	0.20	N	80	U	M	S
		2	1983	0.05					
SHI	18	1	1959	0.31	N	80	U	M	S
		2	1985	0.08					
SHI	19	1	1956	0.33	N	80	U	M	S

Cemetery ID	Stone	Inscription #	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Color	Texture
		2	1979	0.12					
SHI	20	1	1976	0.07	N	120	U	M	S
		2	2006	0.04					
SHI	21	1	1978	0.17	N	120	U	F	S
		2	1993	0.15					
SHI	22	1	1979	0.17	N	120	U	W	S
		2	2000	0.04					
		3	2003	0.03					
SHI	23	1	1926	0.49	N	80	U	D	S
		2	1943	0.38					
		3	1988	0.07					
SHI	24	1	1923	0.27	N	80	U	D	S
		2	1952	0.18					
SHI	25	1	1922	0.49	N	80	U	M	R
		2	1924	0.36					
		3	1932	0.42					
SHI	26	1	1927	0.70	N	80	U	F	R
		2	1979	0.08					
SOA	52	1	1905	0.63	Y	90	U	F	S
		2	1917	0.63					
		3	1927	0.50					
SOA	53	1	1898	0.25	Y	90	U	M	S
		2	1905	0.28					
		3	1929	0.21					
SOA	54	1	1896	0.81	Y	90	U	D	S
		2	1905	0.70					
		3	1919	0.73					
		4	1950	0.20					
SOA	55	1	1897	0.53	N	90	U	D	S
		2	1905	0.57					
SOA	56	1	1900	0.49	Y	90	U	M	S
		2	1905	0.49					
SOA	57	1	1905	0.50	Y	90	U	M	S
		2	1936	0.40					
SOA	58	1	1902	0.52	Y	90	U	D	S
		2	1905	0.48					

Cemetery ID	Stone	Inscription #	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Color	Texture
SOA	59	1	1904	0.55	Y	90	U	M	S
		2	1905	0.58					
		3	1942	0.28					
		4	1949	0.23					
		5	1943	0.19					
SOA	60	1	1903	0.90	N	270	U	M	S
		2	1905	0.92					
SOA	61	1	1903	0.71	N	270	U	D	S
		2	1905	0.66					
SOA	62	1	1850	0.76	N	90	U	M	R
		2	1905	0.80					
		3	1908	0.83					
SOA	63	1	1905	0.81	N	90	U	M	R
		2	1912	0.85					
SOA	64	1	1905	0.75	Y	270	U	M	S
		2	1916	0.88					
		3	1918	0.81					
SOA	65	1	1905	0.78	N	0	U	D	S
		2	1910	0.60					
		3	1913	0.66					
		4	1925	0.50					
		5	1930	0.31					
		6	1942	0.29					
SOA	66	1	1905	0.69	N	0	U	D	S
		2	1927	0.47					
SOA	67	1	1927	0.25	Y	90	U	D	S
		2	1938	0.25					
		3	1978	0.10					
SOA	68	1	1927	0.48	Y	90	U	F	S
		2	1934	0.62					
		3	1948	0.61					
		4	1950	0.40					
SOA	69	1	1927	0.37	Y	90	U	M	S
		2	1943	0.26					
SOA	70	1	1927	0.52	N	90	U	D	S
		2	1958	0.21					

Cemetery ID	Stone	Inscription #	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Color	Texture
SOA	71	1	1927	0.48	Y	.	U	W	R
		2	1940	0.53					
		3	1949	0.46					
SOA	72	1	1927	1.00	Y	90	U	D	S
		2	1944	0.73					
SOA	73	1	1925	0.21	Y	90	U	D	S
		2	1927	0.22					
		3	1945	0.22					
SOA	74	1	1927	0.54	Y	90	U	D	S
		2	1941	0.41					
SOA	75	1	1927	0.49	Y	90	U	D	S
		2	1936	0.43					
SOA	76	1	1927	0.51	Y	90	U	D	S
		2	1938	0.43					
SOA	77	1	1927	0.51	Y	90	U	M	S
		2	1937	0.38					
		3	1938	0.20					
SOA	78	1	1927	0.56	Y	90	U	D	S
		2	1935	0.37					
SOA	79	1	1927	0.37	Y	90	U	D	S
		2	1948	0.27					
SOA	80	1	1927	0.45	N	90	U	D	S
		2	1937	0.29					
SOA	81	1	1921	0.55	N	90	U	D	S
		2	1927	0.48					
WAL	1	1	1916	0.80	N	120	U	M	S
		2	1939	0.50					
		3	1942	0.49					
WAL	2	1	1928	0.81	N	120	U	M	S
		2	1958	0.32					
WAL	3	1	1916	0.73	N	120	U	M	S
		2	1918	0.64					
WAL	4	1	1943	0.48	N	120	U	M	S
		2	1954	0.39					
WAL	5	1	1948	0.60	N	120	U	F	S
		2	1976	0.24					

Cemetery ID	Stone	Inscription #	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Color	Texture
WAL	6	1	1909	1.07	N	300	U	D	S
		2	1911	1.06					
WAL	7	1	1912	0.45	N	.	U	M	S
		2	1948	0.27					
WAL	8	1	1902	1.05	N	120	U	F	R
		2	1930	1.03					
		3	1933	1.00					
		4	1937	1.05					
WAL	9	1	1909	1.08	N	120	U	M	S
		2	1932	0.58					
WAL	10	1	1951	0.69	N	120	U	M	S
		2	1967	0.27					
WAL	11	1	1968	0.54	N	220	U	M	R
		2	1985	0.07					
WAL	12	1	1961	0.61	N	0	U	F	S
		2	1993	0.13					
		3	1997	0.03					
WAL	13	1	1961	0.36	N	0	U	M	S
		2	1992	0.01					
WAL	14	1	1960	0.74	N	180	U	W	S
		2	1987	0.29					
		3	1990	0.16					
WAL	15	1	1971	0.06	N	210	U	F	S
		2	1985	0.02					
WAL	16	1	1962	0.55	N	210	U	W	S
		2	2007	0.01					
WAL	17	1	1964	0.42	N	210	U	W	S
		2	2005	0.01					
WAL	18	1	1935	0.82	N	100	U	D	S
		2	1963	0.26					
WAL	19	1	1932	0.61	N	100	U	M	S
		2	1954	0.31					
WAL	20	1	1933	0.83	N	100	U	M	S
		2	1984	0.03					
WBR	1	1	1910	1.11	N	310	U	D	S
		2	1912	1.19					

Cemetery ID	Stone	Inscription #	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Color	Texture
		3	1929	0.88					
WBR	2	1	1966	0.54	N	110	U	W	S
		2	1972	0.27					
		3	1978	0.23					
WBR	3	1	1965	0.39	N	110	U	W	S
		2	1978	0.22					
		3	1998	0.07					
WBR	4	1	1966	0.22	N	110	U	M	S
		2	1983	0.09					
WBR	5	1	1965	0.14	N	110	U	D	S
		2	1984	0.08					
WBR	6	1	1976	0.10	N	110	U	M	S
		2	1994	0.02					
WBR	7	1	1977	0.15	N	110	U	W	S
		2	1988	0.14					
WBR	8	1	1977	0.11	N	110	U	W	S
		2	1991	0.05					
WBR	9	1	1982	0.05	N	110	U	M	S
		2	1994	0.01					
WBR	10	1	1982	0.10	N	110	U	M	S
		2	1997	0.03					
WBR	11	1	1929	0.89	N	110	U	M	S
		2	1938	0.79					
WBR	12	1	1928	0.77	N	110	U	D	S
		2	1954	0.40					
WBR	13	1	1927	0.93	N	110	U	M	S
		2	1954	0.52					
WBR	14	1	1929	1.21	N	110	U	M	S
		2	1937	1.12					
		3	1941	1.00					
WBR	15	1	1928	1.18	N	110	U	M	S
		2	1934	1.19					
WBR	16	1	1928	1.02	Y	110	U	D	S
		2	1942	0.58					
WBR	17	1	1904	1.24	N	290	U	D	S
		2	1908	1.20					

Cemetery ID	Stone	Inscription #	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Color	Texture
		3	1928	0.68					
		4	1933	0.53					
WBR	18	1	1926	0.76	N	290	U	D	S
		2	1927	0.78					
		3	1963	0.21					
WBR	19	1	1926	0.85	N	290	U	M	S
		2	1935	0.62					
		3	1950	0.21					
WBR	20	1	1927	0.77	N	290	U	M	S
		2	1934	0.83					
		3	1958	0.24					
WBR	21	1	1908	1.25	Y	290	U	M	S
		2	1913	1.46					
WBR	22	1	1908	0.93	N	290	U	D	S
		2	1923	0.94					
		3	1979	0.04					
WBR	23	1	1907	1.24	N	290	U	D	S
		2	1953	0.48					
WBR	24	1	1872	2.10	N	110	U	D	R
WBR	25	1	1966	0.69	N	110	U	W	S
		2	2008	0.12					
WBR	26	1	1967	0.40	N	110	U	W	S
		2	2003	0.07					
WBR	27	1	1997	0.09	N	110	U	F	S
		2	2002	0.04					
WOR	1	1	1934	0.60	N	90	U	W	S
		2	1966	0.29					
WOR	2	1	1924	0.17	N	90	U	M	S
		2	1947	0.17					
		3	1953	0.15					
WOR	3	1	1922	0.34	N	90	U	M	S
		2	1923	0.22					
WOR	4	1	1937	0.25	Y	90	U	D	S
		2	1941	0.15					
WOR	5	1	1951	0.17	Y	90	U	M	S
		2	1954	0.18					

Cemetery ID	Stone	Inscription #	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Color	Texture
WOR	6	1	1950	0.21	N	90	U	D	S
		2	1951	0.17					
WOR	7	1	1977	0.04	N	90	U	M	S
		2	1984	0.05					
WOR	8	1	1909	0.28	Y	90	U	M	S
		2	1917	0.24					
WOR	9	1	1950	0.28	N	90	U	D	S
		2	1963	0.13					
YAR	1	1	1907	0.92	N	90	U	M	R
		2	1915	1.10					
		3	1922	0.86					
YAR	2	1	1925	0.77	N	90	U	M	S
		2	1957	0.54					
		3	1957	0.49					
		4	1980	0.14					
		5	1981	0.14					
YAR	3	1	1932	0.41	N	90	U	F	S
		2	1967	0.30					
		3	1971	0.27					
YAR	4	1	1913	0.96	N	90	U	D	S
		2	1913	1.09					
		3	1929	0.88					
		4	1944	0.62					
		5	2001	0.01					
YAR	5	1	1910	0.57	N	90	U	D	S
		2	1940	0.52					
		3	1963	0.10					
YAR	6	1	1913	1.41	N	90	U	W	S
		2	1915	1.43					
		3	1971	0.34					
YAR	7	1	1927	0.76	N	90	U	F	S
		2	1960	0.34					
		3	1992	0.06					
YAR	8	1	1911	0.84	N	90	U	M	R
		2	1944	0.49					
YAR	9	1	1955	0.60	N	90	U	W	S

Cemetery ID	Stone	Inscription #	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Color	Texture
		2	1969	0.45					
		3	1976	0.34					
YAR	10	1	1920	1.10	N	300	U	F	S
		2	1931	0.96					
		3	1964	0.17					
YAR	11	1	1957	0.82	N	300	U	M	S
		2	1984	0.17					
		3	1995	0.14					
YAR	12	1	1957	0.59	N	300	U	M	S
		2	1970	0.37					
		3	1991	0.12					
YAR	13	1	1957	0.21	N	300	U	M	S
		2	1979	0.05					
YAR	14	1	1958	0.80	N	300	U	W	S
		2	2003	0.11					
YAR	15	1	1959	0.50	N	300	U	W	S
		2	1965	0.51					
		3	2006	0.01					
YAR	16	1	1959	0.45	N	300	U	M	S
		2	1982	0.05					
YAR	17	1	1970	0.26	N	300	U	W	S
		2	2000	0.07					
YAR	18	1	1943	0.20	N	300	U	D	S
		2	1956	0.21					
YAR	19	1	1967	0.30	Y	300	U	F	S
		2	1986	0.05					
YAR	20	1	1950	0.70	N	300	U	W	S
		2	2008	0.00					
YAR	21	1	1912	0.49	Y	300	U	F	S
		2	1931	0.39					
YAR	22	1	1905	0.73	Y	300	U	M	S
		2	1910	0.73					
YAR	23	1	1894	0.28	Y	300	U	D	S
		2	1909	0.38					
		3	1918	0.33					
		4	1931	0.25					

Cemetery ID	Stone	Inscription #	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Color	Texture
YAR	24	1	1891	0.76	N	300	U	M	S
		2	1928	0.76					
		3	1930	0.71					
		4	1940	0.56					
YAR	25	1	1885	0.31	Y	300	U	M	S
		2	1898	0.33					
		3	1912	0.35					
		4	1913	0.29					
		5	1947	0.16					
		6	1949	0.16					
		7	1955	0.13					
YAR	26	1	1938	0.44	Y	300	U	M	S
		2	1949	0.40					
YAR	27	1	1899	0.46	Y	300	U	D	S
		2	1920	0.39					
		3	1922	0.37					
		4	1952	0.23					
YAR	28	1	1901	0.72	Y	300	U	D	S
		2	1907	0.66					
		3	1948	0.47					
YAR	29	1	1900	0.81	Y	300	U	D	S
		2	1918	0.26					
		3	1956	0.28					
YAR	30	1	1902	0.65	N	300	U	D	S
		2	1917	0.52					
		3	1917	0.44					
		4	1944	0.20					

2005-2008 Dataset (H. D. Mooers, unpublished data)

Variable information gathered for the 2005-2008 dataset are listed with the same characters as defined for the 2010 dataset. Blanks represent where variable information was not collected.

Cemetery ID	Stone	Inscription	Yr Measured	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Texture	Color
BEN	1	1	2005	1906	0.74					
		2	2005	1916	0.81					
		3	2005	1927	0.82					
BEN	2	1	2005	1959	0.29					
		2	2005	1964	0.14					
BEN	3	1	2005	1952	0.65					
		2	2005	1967	0.26					
BEN	4	1	2005	1955	0.42					
		2	2005	1965	0.22					
BEN	5	1	2005	1916	1.28					
BEN	6	1	2005	1924	1.80					
		2	2005	1930	1.84					
BEN	7	1	2005	1927	0.67					
BEN	8	1	2005	1927	0.96					
		2	2005	1971	0.24					
BEN	9	1	2005	1905	0.83					
		2	2005	1920	0.95					
BRO	1	1	2006	1911	0.20					
		2	2006	1935	0.18					
BRO	2	1	2006	1906	0.81					
		2	2006	1913	0.80					
BRO	3	1	2006	1935	0.30					
BRO	4	1	2006	1903	0.40					
		2	2006	1912	0.24					
BRO	5	1	2006	1922	0.19					
		2	2006	1953	0.22					
BRO	6	1	2006	1921	0.29					
		2	2006	1933	0.33					
BRO	7	1	2006	1924	0.24					
		2	2006	1938	0.23					
BRO	8	1	2006	1902	0.48					
BRO	9	1	2006	1887	0.36					
		2	2006	1899	0.39					

Cemetery ID	Stone	Inscription	Yr Measured	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Texture	Color
BRO	10	1	2006	1949	0.11					
		2	2006	1961	0.12					
BRO	11	1	2006	1955	0.17					
		2	2006	1980	0.16					
BRO	12	1	2006	1956	0.08					
		2	2006	1996	0.02					
BRO	13	1	2006	1960	0.12					
		2	2006	1980	0.05					
COV	1	1	2005	1884	0.63					
		2	2005	1945	0.52					
COV	2	1	2005	1896	0.96					
COV	3	1	2005	1874	0.66					
		2	2005	1909	0.60					
COV	4	1	2005	1870	0.78					
		2	2005	1896	0.42					
COV	5	1	2005	1876	0.87					
COV	6	1	2005	1887	0.41					
		2	2005	1931	0.34					
DUD	1	1	2007	1928	0.59					
		2	2007	1942	0.43					
DUD	2	1	2007	1922	0.99					
		2	2007	1938	1.16					
DUD	3	1	2007	1957	0.67					
DUD	4	1	2007	1923	0.82					
		2	2007	1958	0.40					
DUD	5	1	2007	2006	0.00					
DUD	6	1	2007	1976	0.15					
		2	2007	1985	0.08					
DUD	7	1	2007	1936	0.56					
		2	2007	1957	0.30					
DUD	8	1	2007	1966	0.30					
		2	2007	2000	0.02					
DUD	9	1	2007	1923	0.96					
		2	2007	1928	0.95					
DUD	10	1	2007	1924	0.74					
		2	2007	1943	0.50					

Cemetery ID	Stone	Inscription	Yr Measured	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Texture	Color
DUD	11	1	2007	1981	0.08					
HAD	1	1	2006	1909	0.41					
		2	2006	1922	0.40					
HAD	2	1	2006	1896	0.37					
		2	2006	1907	0.34					
HAD	3	1	2006	1960	0.05					
		2	2006	1988	0.06					
HAD	4	1	2006	1931	0.35					
HAD	5	1	2006	1941	0.33					
HAD	6	1	2006	1909	0.31					
		2	2006	1930	0.33					
HAD	7	1	2006	1933	0.48					
		2	2006	1940	0.30					
HAD	8	1	2006	1958	0.10					
HAD	9	1	2006	1982	0.13					
		2	2006	1991	0.05					
HAD	10	1	2006	1925	0.16					
		2	2006	1930	0.15					
		3	2006	1939	0.15					
		4	2006	1965	0.15					
HAD	11	1	2006	1906	0.40					
		2	2006	1918	0.46					
JQK	1	1	2006	1870	2.37					
		2	2006	1872	2.51					
		3	2006	1899	2.27					
		4	2006	1909	1.57					
		5	2006	1933	1.09					
		6	2006	1940	0.86					
JQK	2	1	2006	1880	2.40					
		2	2006	1902	1.90					
JQK	3	1	2006	1882	1.45					
		2	2006	1898	1.38					
		3	2006	1910	1.13					
		4	2006	1913	1.00					
		5	2006	1928	0.72					
JQK	4	1	2006	1953	0.67					

Cemetery ID	Stone	Inscription	Yr Measured	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Texture	Color
		2	2006	1964	0.41					
		3	2006	1990	0.03					
JQK	5	1	2006	1954	0.39					
		2	2006	1959	0.19					
JQW	1	1	2005	1888	3.02					
		2	2005	1937	1.95					
JQW	2	1	2005	1867	1.51					
		2	2005	1896	1.62					
JQW	3	1	2005	1934	1.64					
JQW	4	1	2005	1949	1.02					
		2	2005	1992	0.11					
JQW	5	1	2005	1933	1.32					
		2	2005	1953	0.89					
		3	2005	1966	0.35					
JQW	6	1	2005	1879	3.07					
		2	2005	1900	2.37					
JQW	7	1	2005	1875	3.46					
		2	2005	1880	3.66					
		3	2005	1896	3.87					
		4	2005	1919	2.46					
JQW	8	1	2006	1959	0.61					
		2	2006	1966	0.43					
JQW	9	1	2006	1932	1.17					
		2	2006	1943	1.35					
		3	2006	1964	0.57					
		4	2006	1985	0.14					
JQW	10	1	2006	1946	1.04					
		2	2006	1977	0.12					
		3	2006	1983	0.02					
KHE	1	1	2006	1913	0.50					
		2	2006	1944	0.48					
		3	2006	1960	0.31					
		4	2006	1970	0.25					
		5	2006	1970	0.18					
		6	2006	1980	0.10					
KHE	2	1	2006	1912	0.48					

Cemetery ID	Stone	Inscription	Yr Measured	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Texture	Color
		2	2006	1949	0.25					
KHE	3	1	2006	1913	0.54					
		2	2006	1951	0.23					
KHE	4	1	2006	1929	0.28	Y				
		2	2006	1938	0.24					
		3	2006	1950	0.28					
KHE	5	1	2006	1901	0.55					
		2	2006	1927	0.57					
		3	2006	1951	0.32					
KHE	6	1	2006	1902	0.57					
		2	2006	1912	0.64					
		3	2006	1913	0.52					
		4	2006	1929	0.48					
KHE	7	1	2006	1901	0.47					
		2	2006	1937	0.38					
KHE	8	1	2006	1899	0.53	Y				
		2	2006	1904	0.47					
		3	2006	1942	0.22					
KHE	9	1	2006	1899	0.39					
		2	2006	1942	0.13					
KHE	10	1	2006	1900	0.34	Y				
		2	2006	1904	0.41					
		3	2006	1929	0.31					
KHE	11	1	2006	1905	0.41					
		2	2006	1923	0.47					
		3	2006	1931	0.34					
KHE	12	1	2006	1905	0.54					
		2	2006	1920	0.45					
		3	2006	1937	0.29					
KHE	13	1	2006	1903	0.75					
		2	2006	1919	0.84					
		3	2006	1957	0.29					
		4	2006	1968	0.14					
KHE	14	1	2006	1912	0.47					
		2	2006	1937	0.46					
		3	2006	1944	0.32					

Cemetery ID	Stone	Inscription	Yr Measured	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Texture	Color
KID	1	1	2005	1936	0.48					
KID	2	1	2005	1944	0.27					
		2	2005	1972	0.13					
KID	3	1	2005	1898	0.41					
		2	2005	1925	0.42					
		3	2005	1932	0.46					
KID	4	1	2005	1883	1.09					
KID	5	1	2005	1929	0.67					
KID	6	1	2005	1888	0.64					
KID	7	1	2005	1888	0.47					
		2	2005	1945	0.39					
KID	8	1	2005	1915	0.40					
		2	2005	1927	0.38					
KID	9	1	2005	1895	0.71					
		2	2005	1912	0.71					
KNO	1	1	2005	1924	0.81					
KNO	2	1	2005	1924	0.28					
		2	2005	1940	0.31					
		3	2005	1951	0.23					
KNO	4	1	2005	1913	0.50					
KNO	6	1	2006	1908	0.81					
		2	2006	1916	0.81					
		3	2006	1928	0.85					
KNO	7	1	2006	1934	0.38					
		2	2006	1940	0.32					
KNO	8	1	2006	1934	0.33					
		2	2006	1941	0.34					
KNO	9	1	2006	1935	0.49					
		2	2006	1953	0.25					
KNO	10	1	2006	1936	0.75					
		2	2006	1980	0.07					
		3	2006	1984	0.05					
KNO	11	1	2006	1938	0.91					
		2	2006	1965	0.46					
KNO	12	1	2006	1937	0.52					
		2	2006	1972	0.11					

Cemetery ID	Stone	Inscription	Yr Measured	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Texture	Color
KNO	13	1	2006	1966	0.31					
		2	2006	1969	0.34					
		3	2006	1978	0.04					
		4	2006	1999	0.02					
KNO	14	1	2006	1983	0.20					
		2	2006	2002	0.06					
LYE	1	1	2005	1881	1.23					
		2	2005	1906	1.04					
		3	2005	1925	0.62					
LYE	2	1	2005	1894	1.30					
		2	2005	1901	1.45					
LYE	3	1	2005	1883	1.32					
		2	2005	1893	1.17					
		3	2005	1906	1.08					
		4	2005	1926	0.97					
LYE	4	1	2005	1932	1.01					
LYE	5	1	2005	1900	0.82					
		2	2005	1911	0.89					
LYE	6	1	2005	1917	0.91					
		2	2005	1963	0.24					
PPA	1	1	2005	1895	0.28					
		2	2005	1894	0.28					
		3	2005	1936	0.15					
PPA	2	1	2005	1942	0.27					
		2	2005	1926	0.21					
PPA	3	1	2005	1891	0.29					
		2	2005	1908	0.27					
PPA	4	1	2005	1896	0.28					
		2	2005	1918	0.32					
		3	2005	1944	0.22					
PPA	5	1	2005	1896	0.16					
		2	2005	1903	0.16					
		3	2005	1935	0.22					
PPA	6	1	2005	1904	0.33					
		2	2005	1945	0.28					
PRE	1	1	2005	1899	0.30					

Cemetery ID	Stone	Inscription	Yr Measured	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Texture	Color
		2	2005	1901	0.26					
		3	2005	1917	0.30					
PRE	2	1	2005	1895	0.58					
		2	2005	1919	0.59					
		3	2005	1942	0.26					
PRE	3	1	2005	1891	0.52					
		2	2005	1927	0.42					
PRE	4	1	2005	1889	0.61					
PRE	5	1	2005	1931	0.25					
		2	2005	1936	0.21					
		3	2005	1916	0.18					
		4	2005	1930	0.20					
RED	1	1	2005	1879	0.97					
		2	2005	1895	0.80					
RED	2	1	2005	1917	0.50					
RED	3	1	2005	1910	0.60					
RED	4	1	2005	1928	0.63					
RED	5	1	2005	1935	0.77					
		2	2005	1984	0.07					
RED	6	1	2005	1932	0.69					
		2	2005	1959	0.33					
RED	7	1	2005	1882	0.27					
RED	8	1	2005	1857	0.63					
SAN	1	1	2008	1938	0.42	N		L	D	
		2	2008	1963	0.29					
		3	2008	1979	0.03					
SAN	2	1	2008	1938	0.92	N		L	M	
		2	2008	1965	0.38					
		3	2008	1985	0.11					
SAN	3	1	2008	1935	0.60	Y		L	M	
		2	2008	1963	0.19					
SAN	4	1	2008	1933	0.84	N		L	F	
		2	2008	1962	0.44					
SAN	5	1	2008	1934	0.74	N		L	M	
		2	2008	1946	0.71					
		3	2008	1964	0.34					

Cemetery ID	Stone	Inscription	Yr Measured	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Texture	Color
SAN	6	1	2008	1933	0.72	N		L	D	
		2	2008	1937	0.73					
		3	2008	1962	0.19					
SAN	7	1	2008	1933	1.36	N		L	W	
		2	2008	1960	0.63					
		3	2008	1964	0.54					
SAN	8	1	2008	1949	0.77	N		H	F	
		2	2008	1968	0.35					
SAN	9	1	2008	1951	0.86			H		
		2	2008	1984	0.08					
SAN	10	1	2008	1962	0.56	N		H	F	
		2	2008	1987	0.09					
SAN	11	1	2008	1954	0.88	N		H	F	
		2	2008	1970	0.24					
		3	2008	1982	0.09					
SAN	12	1	2008	1957	0.66	N		H	M	
		2	2008	1973	0.19					
SAN	13	1	2008	1946	0.78	N		H	W	
		2	2008	1956	0.58					
		3	2008	1976	0.09					
SAN	14	1	2008	1927	2.14	N		H	F	R
		2	2008	1965	0.80					
		3	2008	1979	0.25					
SCO	1	1	2005	1899	1.01					
		2	2005	1938	0.58					
SCO	2	1	2005	1911	0.76					
		2	2005	1925	0.62					
SCO	3	1	2005	1905	0.90					
		2	2005	1911	0.85					
		3	2005	1954	0.41					
		4	2005	1969	0.15					
SCO	4	1	2005	1932	0.49					
		2	2005	1945	0.38					
SCO	5	1	2005	1888	0.73					
		2	2005	1919	0.58					
		3	2005	1926	0.30					

Cemetery ID	Stone	Inscription	Yr Measured	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Texture	Color
SCO	6	1	2005	1893	1.01					
		2	2005	1912	0.84					
		3	2005	1952	0.65					
SCO	7	1	2005	1903	0.82					
		2	2005	1933	0.64					
SCR	1	1	2008	1908	0.79					
		2	2008	1911	0.67					
SCR	2	1	2008	1979	0.08					
		2	2008	1998	0.03					
SCR	3	1	2008	1973	0.14					
SCR	4	1	2008	1971	0.09					
		2	2008	1982	0.06					
SCR	6	1	2008	1906	0.44					
		2	2008	1912	0.34					
SCR	7	1	2008	1889	0.26					
		2	2008	1890	0.23					
SCR	8	1	2008	1936	0.40					
SHI	1	1	2005	1919	0.63					
		2	2005	1916	0.59					
		3	2005	1923	0.68					
SHI	2	1	2005	1920	0.46					
		2	2005	1935	0.38					
SHI	3	1	2005	1927	0.82					
		2	2005	1979	0.07					
SHI	4	1	2005	1957	0.61					
		2	2005	1980	0.18					
SHI	5	1	2005	1945	0.42					
		2	2005	1973	0.22					
SHI	6	1	2005	1967	0.43					
		2	2005	1964	0.17					
SOA	1	1	2006	1976	0.23					
		2	2006	1990	0.03					
SOA	2	1	2006	1975	0.43					
SOA	3	1	2006	1975	0.41					
		2	2006	1984	0.14					
SOA	4	1	2006	1976	0.08					

Cemetery ID	Stone	Inscription	Yr Measured	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Texture	Color
SOA	5	1	2006	1909	0.98					
		2	2006	1916	1.06					
SOA	6	1	2006	1965	0.19					
		2	2006	1998	0.04					
SOA	7	1	2006	1915	0.70					
		2	2006	1915	0.92					
SOA	8	1	2006	1896	1.51					
SOA	9	1	2006	1897	0.53					
SOA	10	1	2006	1897	0.53					
SOA	11	1	2006	1898	1.09					
		2	2006	1909	1.19					
SOA	12	1	2006	1898	0.56					
		2	2006	1912	0.56					
SOA	13	1	2006	1898	0.86					
		2	2006	1910	0.76					
SOA	14	1	2006	1898	1.49	Y				
		2	2006	1928	0.99					
SOA	15	1	2006	1900	0.52					
		2	2006	1932	0.27					
SOA	16	1	2006	1901	0.78					
		2	2006	1931	0.31					
SOA	17	1	2006	1918	1.22					
		2	2006	1923	1.17					
		3	2006	1959	0.35					
SOA	18	1	2006	1918	0.54					
		2	2006	1979	0.45					
		3	2006	2004	0.02					
SOA	19	1	2006	1919	0.41					
		2	2006	1947	0.24					
SOA	20	1	2006	1916	0.50					
		2	2006	1945	0.27					
SOA	21	1	2006	1918	1.46					
		2	2006	1941	0.65					
		3	2006	1961	0.35					
SOA	22	1	2006	1921	0.47					
		2	2006	1945	0.34					

Cemetery ID	Stone	Inscription	Yr Measured	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Texture	Color
		3	2006	1966	0.10					
SOA	23	1	2006	1982	0.19					
		2	2006	2005	0.02					
SOA	24	1	2006	1982	0.16					
		2	2006	2005	0.00					
SOA	25	1	2006	1983	0.17					
		2	2006	1992	0.07					
SOA	26	1	2008	1917	0.53	Y				
		2	2008	1944	0.32					
SOA	27	1	2008	1922	0.48	Y			M	
		2	2008	1956	0.11					
SOA	28	1	2008	1928	0.39	Y				
		2	2008	1969	0.05					
SOA	29	1	2008	1943	0.43				D	
		2	2008	1947	0.30					
		3	2008	1962	0.12					
SOA	30	1	2008	1905	0.81				D	
		2	2008	1919	0.72					
		3	2008	1950	0.24					
SOA	31	1	2008	1967	0.20			L	W	
		2	2008	1972	0.15					
		3	2008	2004	0.00					
SOA	32	1	2008	1966	0.22			L	M	
		2	2008	1990	0.04					
SOA	33	1	2008	1966	0.10			L	D	
		2	2008	1966	0.10					
SOA	34	1	2008	1955	0.43			L	M	
		2	2008	1958	0.38					
		3	2008	1984	0.05					
SOA	35	1	2008	1958	0.13			L	D	
SOA	36	1	2008	1963	0.22			L	W	
		2	2008	1991	0.05					
		3	2008	1994	0.03					
SOA	37	1	2008	1956	0.38			L	W	
SOA	38	1	2008	1955	0.11			L	D	
SOA	39	1	2008	1922	0.26				D	

Cemetery ID	Stone	Inscription	Yr Measured	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Texture	Color
		2	2008	1928	0.31					
		3	2008	1969	0.07					
SOA	40	1	2008	1977	0.14				W	
		2	2008	1991	0.07					
SOA	41	1	2008	1934	0.45				M	
		2	2008	1965	0.10					
SOA	42	1	2008	1957	0.30	Y			M	
		2	2008	1993	0.04					
SOA	43	1	2008	1946	0.58				F	
		2	2008	1959	0.75					
SOA	44	1	2008	1969	0.09				D	
		2	2008	1979	0.06					
SOA	45	1	2008	1969	0.36				W	
		2	2008	2000	0.01					
SOA	46	1	2008	1947	0.23				W	
		2	2008	1976	0.19					
SOA	47	1	2008	1947	0.43				D	
		2	2008	1976	0.10					
SOA	48	1	2008	1947	0.55				M	
		2	2008	1962	0.34					
		3	2008	1983	0.06					
SOA	49	1	2008	1945	0.52	N			W	
		2	2008	1959	0.50					
		3	2008	1974	0.37					
SOA	50	1	2008	1946	0.25				D	
		2	2008	1949	0.20					
		3	2008	1961	0.18					
SOA	51	1	2008	1946	0.46				M	
		2	2008	1973	0.12					
STO	1	1	2007	1933	0.50					
		2	2007	1956	0.18					
STO	2	1	2007	1902	0.27					
		2	2007	1920	0.27					
STO	3	1	2007	2001	0.03					
STO	4	1	2007	1934	0.99					
		2	2007	1960	0.48					

Cemetery ID	Stone	Inscription	Yr Measured	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Texture	Color
STO	5	1	2007	1950	0.18					
		2	2007	1967	0.17					
STO	6	1	2007	1892	0.39					
		2	2007	1897	0.42					
		3	2007	1940	0.50					
STO	7	1	2007	1902	0.72					
		2	2007	1928	0.54					
STO	8	1	2007	1903	0.49					
		2	2007	1918	0.34					
		3	2007	1986	0.05					
STO	9	1	2007	1904	0.81					
		2	2007	1944	0.39					
STO	10	1	2007	1892	0.31					
		2	2007	1919	0.33					
STO	11	1	2007	1901	0.84					
		2	2007	1925	0.63					
		3	2007	1976	0.10					
STO	12	1	2007	1899	0.60					
		2	2007	1939	0.56					
STO	13	1	2007	1894	0.50					
		2	2007	1918	0.41					
STO	14	1	2007	1947	0.17					
		2	2007	1976	0.06					
STO	15	1	2007	1920	0.64					
		2	2007	1933	0.46					
		3	2007	1967	0.20					
STO	16	1	2007	1967	0.42					
		2	2007	2002	0.02					
STO	17	1	2007	1904	0.41					
		2	2007	1938	0.26					
STO	18	1	2007	1950	0.44					
		2	2007	1984	0.09					
TAM	1	1	2005	1899	0.99					
TAM	2	1	2005	1896	1.37					
TAM	3	1	2005	1888	1.43	Y				
TAM	4	1	2005	1883	1.13					

Cemetery ID	Stone	Inscription	Yr Measured	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Texture	Color
TAM	5	1	2005	1937	0.63					
TAM	6	1	2005	1964	0.25					
TAM	7	1	2005	1927	0.89					
TIP	1	1	2007	1952	0.77					
		2	2007	1989	0.14					
TIP	2	1	2007	1952	0.34					
		2	2007	1969	0.28					
TIP	3	1	2007	1950	1.31					
		2	2007	1957	0.78					
		3	2007	1960	0.61					
TIP	4	1	2007	1918	0.79					
		2	2007	1944	0.66					
TIP	5	1	2007	1915	1.09					
		2	2007	1937	0.85					
TIP	6	1	2007	1909	0.93					
		2	2007	1923	0.97					
		3	2007	1934	0.88					
TIP	7	1	2007	1913	1.00					
		2	2007	1954	0.57					
WAR	1	1	2005	1896	0.33					
		2	2005	1918	0.21					
WAR	2	1	2005	1882	0.46					
WAR	3	1	2005	1964	0.23					
		2	2005	1997	0.05					
WAR	4	1	2005	1885	0.34					
WAR	5	1	2005	1902	0.39					
WIT	2	1	2006	1882	0.82					
		2	2006	1917	0.80					
WIT	3	1	2006	1880	1.26					
		2	2006	1887	1.22					
		3	2006	1896	1.51					
		4	2006	1904	1.41					
WIT	4	1	2006	1909	1.35					
		2	2006	1928	1.19					
WIT	5	1	2006	1903	0.71					
		2	2006	1949	0.50					

Cemetery ID	Stone	Inscription	Yr Measured	Year*	Depth** (mm/yr)	Tree	Aspect	Elev.	Texture	Color
WIT	6	1	2006	1884	0.86					
WIT	7	1	2006	1890	0.90					
		2	2006	1921	0.87					
WIT	8	1	2006	1952	0.84					
		2	2006	1994	0.10					
		3	2006	1998	0.05					
WIT	9	1	2006	1950	0.31					
		2	2006	1976	0.08					
WIT	10	1	2006	1955	0.40					
		2	2006	1987	0.13					
WIT	11	1	2006	1962	0.37					
		2	2006	1970	0.28					
		3	2006	1994	0.10					