GROUNDWATER CONTAMINANT CONCENTRATIONS OF LAND USE CATEGORIES FOR THE BARTON SPRINGS EDWARDS AQUIFER, TEXAS

THESIS

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by

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San Marcos, Texas
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GROUNDWATER CONTAMINANT CONCENTRATIONS

OF LAND USE CATEGORIES FOR THE BARTON

SPRINGS EDWARDS AQUIFER, TEXAS

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ABSTRACT

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Fourteen groundwater contaminants across the Barton Springs segment of the Edwards Aquifer, Texas were monitored in order to test whether there is a significant correlation between their concentrations and land uses. The Kruskall-Wallis test was applied to each contaminant's data set to test for differences in the median contaminant concentrations between each land use type. Regression analysis is also performed to determine whether the groundwater contaminant concentrations can be predicted based on percentage of each land use type. Six of the contaminants (DB, Nitrobenzene, Phenol, Terphenyl, Tribromophenol, and Triphenyl Phosphate) showed correlation between concentration and the land use type, while quadratic regression proved to be the best regression model for prediction of the contaminant concentrations based on above ground percentage land use type area. Further work is still needed to verify the importance of land use applications and groundwater contaminant levels across the aquifer.

CHAPTER I

INTRODUCTION TO STUDY

Objective

The purpose of this research is to establish whether there is a difference in the groundwater contaminant concentrations of various land uses for the Barton Springs Edwards Aquifer (BSEA), Texas.

Rationale

The Edwards Aquifer is a critical source of water for the rapidly expanding I-35 corridor region between Austin and San Antonio. It is important to understand the implications of land use development on present and potential groundwater supplies. The unique hydrogeology of the Edwards Aquifer has long been recognized to be sensitive to changes in the overlying surface environment, both locally and regionally, resulting in the potential for the contamination of the groundwater from several possible sources (Brune and Duffin 1983; Woodruff and Slade 1984; Hauwert and Vickers 1994). A further understanding of the contamination potential associated with different land uses will benefit the future water resources management of aquifers in general.

Hypothesis*

H_0 There is no difference in groundwater contaminant concentrations between land uses.

H_1 There is a difference in groundwater contaminant concentrations between land uses.

* At the 95% significance level.

For the above hypothesis, land use categories will be broken down into five categories: industrial, commercial, residential, agricultural and undeveloped. Groundwater contaminant concentrations of 14 industrial and agricultural pollutants will be tested individually, compared between land use type, and assessed for exceedence of maximum contaminant levels set by the 1974 Safe Drinking Water Act (SDWA), (table 1). This study will also ascertain an ability to predict the contaminant concentrations using knowledge of the land uses present.

Table 1. List of groundwater contaminants (Reciprocal Net 2004; ATSDR 2006; Chemical Land 21 2006). Maximum contaminant levels (MCL) derived from modified 1974 Safe Drinking Water Act (SDWA) (EPA 2007).

Contaminant	MCL (µg/L)	Example of Uses	Type
1,2-Dichlorobenzene-d4	600	Air-fresheners/home deodorizers	Industrial Pollutants
2-Fluorobiphenyl	Not listed	Solvent preparation	
2-Fluorophenol	Not listed	Dye preparation	
2,4,6-Tribromophenol	Not listed	Flame retardant- used on rubber/PVC	
4-Bromofluorobenzene	Not listed	Refrigerants, PVC, semiconductors	
Decachlorobiphenyl	Not listed	Capacitor/transistor fluid	
Nitrobenzene-d5	Not listed	Floor polish, paint solvents	
Phenol-d5	Not listed	Industrial resin	
Triphenyl Phosphate	Not listed	Flame retardant- used on rubber/PVC	
2,4-Dichlororphenoxybutyric acid (DB)	70	Herbicide	Agricultural Pollutants
4-Terphenyl-d14	Not listed	Pesticide	
Phorate	Not listed	Pesticide	
Tetrachloro-m-xylene	10,000	Pesticide	
Nitrate	10,000	Fertilizer	

CHAPTER II

LITERATURE REVIEW

This is a review of literature related to the issue of groundwater contaminant concentrations of different land uses for the Barton Springs segment of the Edwards Aquifer, Texas. Several studies have found a significant difference (95%) in groundwater contaminant concentrations between land uses in other aquifers (Cain and Edelmann 1986; Chen and Druliner 1986; Barton, Vowinkel, and Nawyn 1987; Trojan et al 2003). This tendency reflects the increase in urbanization and other anthropogenic development of the land directly overlying the aquifers (Bouwer 1978; Terrene Institute 1994; Pitt et al 1996).

Groundwater Contaminants

Sample Location: A key aspect of this research involves the location of groundwater contaminant sampling. Samples need to be spread out to avoid spatial autocorrelation, where the values at each sample location are significantly correlated with the values at nearby sample locations (Barringer et al 1990, 7). However the choice of sampling locations is commonly determined by the availability of water quality data at certain wells without consideration of the issue of spatial autocorrelation (Cain and Edelmann 1986; Barton, Vowinkel, and Nawyn 1987; Rutledge 1987). The resulting differences in contaminant concentrations between land uses may be biased as a result. Other studies

have demonstrated more freedom in well selection to reduce the impact of spatial autocorrelation. For example, Bruce and McMahon (1996, 132) use a computer grid technique to sample wells and ensure a set distance is established between each sampling point. A different approach to this problem is applied by Trojan and others (2003, 484) by drilling new wells altogether instead of using existing ones, and spacing them out to ensure at least 3 wells are situated at a great enough distance to reduce the impact of spatial autocorrelation in each land use. Both Bruce and McMahon (1996) and Trojan et al (2003) found differences in groundwater contaminant concentration between land uses. In order to establish a clearer relationship, more research is needed into this issue.

Frequency of Sampling: Perhaps the next most critical aspect of the research is the frequency of sampling. Existing studies using only one sample taken at a seemingly random time and date found both less significant differences (Grady and Weaver 1988; Bruce and McMahon 1996) and more significant differences (Anderson and Kristiansen 1984; Chen and Druliner 1986; Eckhardt and Stackelberg 1995) in contaminant concentrations between land use categories at different places. No explanations are given for the particular sampling dates and there is no background information into the conditions during sampling, such as prevailing weather or activities occurring near to the sample site at that time, which could impact the quality of the sample itself. The studies that obtained samples over an extended time period concluded the results were not significant (Katz, Lindner, and Ragone 1980, 615; Esteller and Andreu 1998, 382-83; Trojan et al 2003, 485), but further research is again needed to advance this

hypothesis and cannot be based on these three studies alone, especially because groundwater dynamics and correlations are different in different places.

Selection of Contaminants: Contaminants are usually chosen based on the availability of existing data (Cain, Helsel, and Ragone 1989). Most of the previous research is in agreement as to what base criteria should be measured reflecting the possible sources of these contaminants and whether these sources are found on any of the land uses being studied (Barton, Vowinkel, and Nawyn 1987; Eckhardt and Stackelberg 1995; Bruce and McMahon 1996). Groundwater contaminants include agricultural pollutants (nitrate, sulfate, phosphate, pesticides, and herbicides) and industrial pollutants including volatile organic compounds (VOCs). Several studies found significant differences in nitrate concentration between agricultural and other land uses reflecting fertilizer sources (Chen and Druliner 1986; Eckhardt and Stackelberg 1995; Trojan et al 2003; Babiker et al 2004), while other studies found significant differences in VOC concentration between urban and other land uses, reflecting industrial and automobile pollution sources (Cain and Edelmann 1986; Barton, Vowinkel, and Nawyn 1987; Eckhardt and Stackelberg 1995; Trojan and others 2003). The degree of significance varies between these studies, indicating a need for more data analysis to advance the understanding of contaminant concentrations between land use categories.

Aquifer Properties: The type of aquifer under study is a crucial element of the research as the hydrogeological properties will affect the movement of the groundwater contaminants (Cain and Edelmann 1986, 31; Eckhardt and Stackelberg 1995, 1021). Such

properties include hydraulic conductivity (rate of water flow through an aquifer) and groundwater residence time. Most previous research focuses on alluvial aquifers comprised of sand and gravel. Even these display differing hydrogeological properties amongst themselves, which are estimates, exemplified by their wide ranging figures (Cain and Edelmann 1986, 6; Chen and Druliner 1986, 5; Barton, Vowinkel, and Nawyn 1987, 9-10; Babiker et al 2004, 1011). Other studies give only vague descriptive details about flow such as direction (Anderson and Kristiansen 1984, 210; Martinelli, Minissale, and Verrucchi 1998, 204). The degree of difference in groundwater contaminant concentration between land use categories also varies among these aquifers, maybe reflecting the incomplete aquifer data. Significant differences were found in contaminant concentrations between land use categories (Cain and Edelmann 1986; Eckhardt and Stackelberg 1995; Trojan et al 2003) as were less significant differences (Katz, Lindner, and Ragone 1980; Grady and Weaver 1988; Bruce and McMahon 1996). These respective differences should be approached with caution however, as they are based on estimated aquifer data. The only study focusing on a limestone aquifer was carried out by Rutledge (1987). This also found a less significant difference in groundwater contaminant concentration between land use categories. Again, this finding may be due to the lack of accurate hydrogeological aquifer data. The lack of research into aquifer properties could be limiting to the outcome of any investigation into the differences of groundwater contaminant concentrations between land use categories.

Land Use

Definition of Land Use: The source of land use data used for defining a study area is a major component highlighted in several studies (Cain and Edelmann 1986; Chen and Druliner 1986; Barton, Vowinkel, and Nawyn 1987; Rutledge 1987; Grady and Weaver 1988). Land use can be broken up into 5 main types: industrial, residential, commercial, agricultural and undeveloped (Barton, Vowinkel, and Nawyn 1987; Rutledge 1987; Grady and Weaver 1988). Many of the studies that found differences in contaminant concentrations between land use categories had obtained land use data from local or state agencies that were out-dated (Barton, Vowinkel, and Nawyn 1987; Grady and Weaver 1988; Babiker et al 2004). This would not have taken into account recent changes in land use that may have taken place. Other studies account for this possible source of error by undertaking on-site mapping themselves and hence apply the most up to date land use data (Cain and Edelmann 1986, 11; Rutledge 1987; Bruce and McMahon 1996, 133; Trojan et al 2003, 484). While this may reduce errors arising from outdated sources it does introduce an aspect of human error and also fails to detail individual choices made by the researchers in defining the local land use.

Measurement of Land Use: There are many different methods for determining land use and it is a necessary early step in the research (Cain, Helsel, and Ragone 1989, 233). The use of radii of various sizes to determine the land use around sampling sites has proven popular in several studies that have found differences in contaminant concentration between land use categories (Barton, Vowinkel, and Nawyn 1987; Grady and Weaver 1988; Eckhardt and Stackelberg 1995). This method is chosen to determine the

predominant land use in the sample area and also account for movement of groundwater. Eckhardt and Stackelberg's study (1995, 1021) is particularly precise in defining a 0.5 mile radius in response to the movement of groundwater flow beneath the sample wells. An alternative point of view implies that the use of radii can be misleading in determining the predominant land use (Barringer et al 1990, 4). This classic study, which focuses on the problems involved in relating land use to groundwater contaminants, notes how radii do not fairly represent small, scattered land uses, especially in low resolution land use data which will contain graphical errors. The result is an increase of these errors common in digital data representation of land use. This issue has been aptly dealt with by increasing the radii up-gradient and reducing the radii down-gradient of the sample site. By incorporating a wider field of land use types near to the sample site this data error and misrepresentation are reduced accordingly (Cain and Edelmann 1986, 14). A different approach to this key issue is taken by Rutledge (1987) and Chen and Druliner (1986). These studies determined land use around wells located within a relatively homogenous area, though they do not discuss the criteria used to define 'homogeneity'. The conflicting issues exemplify a need for further research into the matter.

Other Factors Associated with Groundwater Contaminant Sources: The differences in contaminant concentrations between land use categories have already been acknowledged by several researchers (Cain and Edelmann 1986; Chen and Druliner 1986; Trojan et al 2003). However it is also necessary to establish, or at least recognize, that there may be other factors associated with contaminant concentrations. Two studies acknowledge the possible effects of atmospheric sources of contaminants (Lahermo 1988, 34; Bruce and

McMahon 1996, 146). The latter study incorporates an atmospheric factor into the methodology by adding weight to the findings to account for a less significant difference in VOC concentration between urban land use and other land uses. Groundwater pumpage has also been recognized as a possible mechanism reducing contaminant levels through assessing local historical pumping records (Cain and Edelmann 1986, 31; Esteller and Andreu 2005, 384). Generally these factors are merely described and no further light is shed on their possible relationship to groundwater contaminants. Nevertheless, it is apparent that there are conflicting views about factors such as atmospheric contaminant sources and the effects of groundwater pumping and their impacts on groundwater contaminant concentrations requiring further research to establish the significance of their role.

A review of the existing literature reveals that the subject of groundwater contaminant concentrations between land use categories has received wide attention in the past two decades. Several approaches have given varying results depending on local aquifer characteristics and data availability. Further research is necessary in order to increase the understanding of how and why groundwater contaminant concentrations vary between land use categories.

CHAPTER III

METHODOLOGY AND DATA ANALYSIS TECHNIQUES

Study Area

The BSEA is the smallest section of the total Edwards Aquifer, which is divided into three sections overall- the San Antonio or Southern segment (to the south), the Barton Springs segment, and the Northern segment (to the north, fig. 1). The San Antonio segment extends from a groundwater divide near the City of Kyle, about 30 km south of Austin, to near Del Rio in McKinney County.

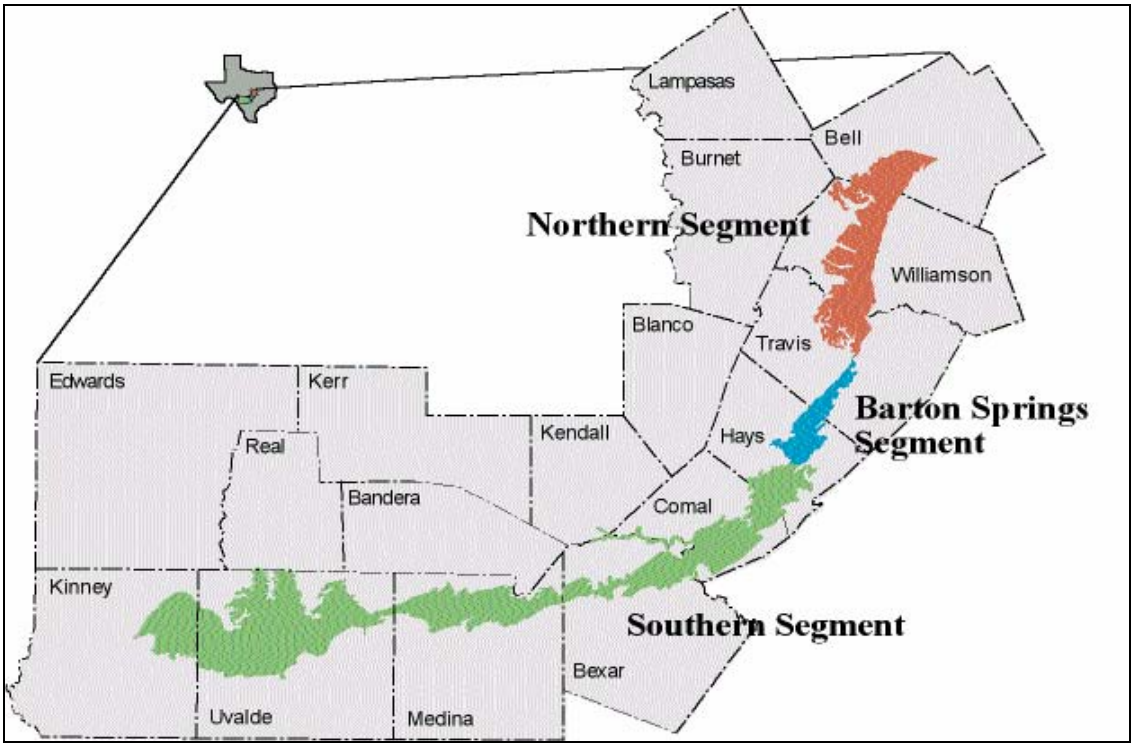

Fig. 1. Edwards Aquifer system. (BSEACD 2007)

The Northern segment of the Edwards Aquifer extends from the Colorado River in Austin to the Northern extreme of the Edwards Limestone in Bell County (BSEACD 2007).

The recharge and artesian unconfined sections of the BSEA, TX are the subject area of this research. This portion of the BSEA covers approximately 330km^2 across southern Travis and northern Hays counties and accounts for the major supply of surface water to the aquifer through infiltration (fig. 2), (Scanlon et al 2003). Water infiltrates freely through the soil in the recharge zone and via vertical sinkholes and cracks in the artesian zone. Annual recharge is estimated to range between 30-50mm depending on annual precipitation across the region (Scanlon n.d.). The contributing area or confined section of the aquifer to the west is not considered in this study as water and contaminants cannot infiltrate the surface through the overlying Del Rio clay to the groundwater below (Scanlon et al 2003).

The BSEA is a limestone aquifer comprised of several layers of karstified limestone. The flow of the groundwater is generally from the southwest to northeast, following the trend of the Balcones Fault Zone to the east of the artesian section (fig. 3), (Woodruff and Slade 1984; R. J. Brandes Company 1999; Scanlon et al 2003).

The rate of flow of the groundwater is variable across the aquifer. Secondary porosity dominates groundwater flow, whereby the water moves longitudinally through sinkholes, caverns and enlarged joints and fractures (Bouwer 1978; R. J. Brandes Company 1999). Subsequently groundwater flow rates have been shown to range from 113 meters/year (Slade, Ruiz, and Slagle 1985) to 2350 km/year (Hauwert, Johns, and Aley 1998), although it should be mentioned that the latter research was biased by

monitoring tracer dies introduced to known recharge features and then artificially flushing the die through the aquifer. A uniform flow rate of 113 meters/year is assumed for this study based on the normal conditions of the former research.

Variables

Groundwater Contaminants- Are defined in this study as agents that make groundwater impure through contact. Samples have been collected once by the Barton Springs Edwards Aquifer Conservation District (BSEACD) during late June and early July 2001 for 31 randomly selected wells located across BSEA (fig. 4), (BSEACD 2001a). The contaminants chosen for this study are common industrial and agricultural pollutants (table 1). These contaminants are chosen based on the availability of the data gathered by BSEACD and their presence at each of the sample wells for statistical analysis. Full sampling techniques are discussed in the BSEACD report (BSEACD 2001b).

The concentrations of each of these contaminants has been tested for each land use category. Groundwater discharge is assumed to be constant throughout the aquifer at the time of sampling, although there were 5 rainfall events which occurred over the aquifer (taken from Kyle and Buda) during sampling which may have flushed any groundwater contaminants through the aquifer (fig. 5). The assumption that a constant flow is reasonable because the rainfall events were only minor, all less than 14mm (0.5 inches).

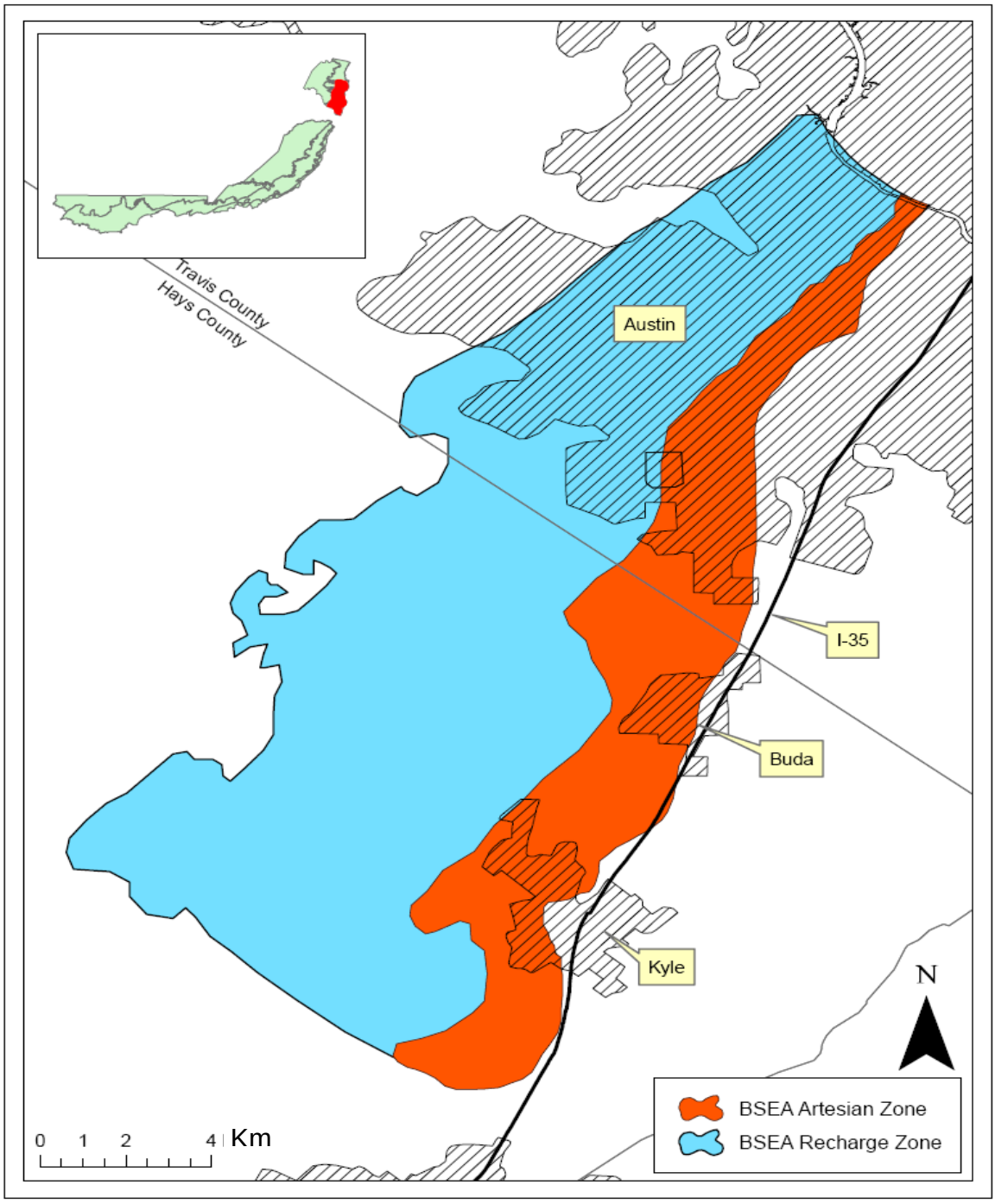

Fig. 2. Location of Barton Springs segment within Edwards Aquifer system (inset). (TWDB 1997)

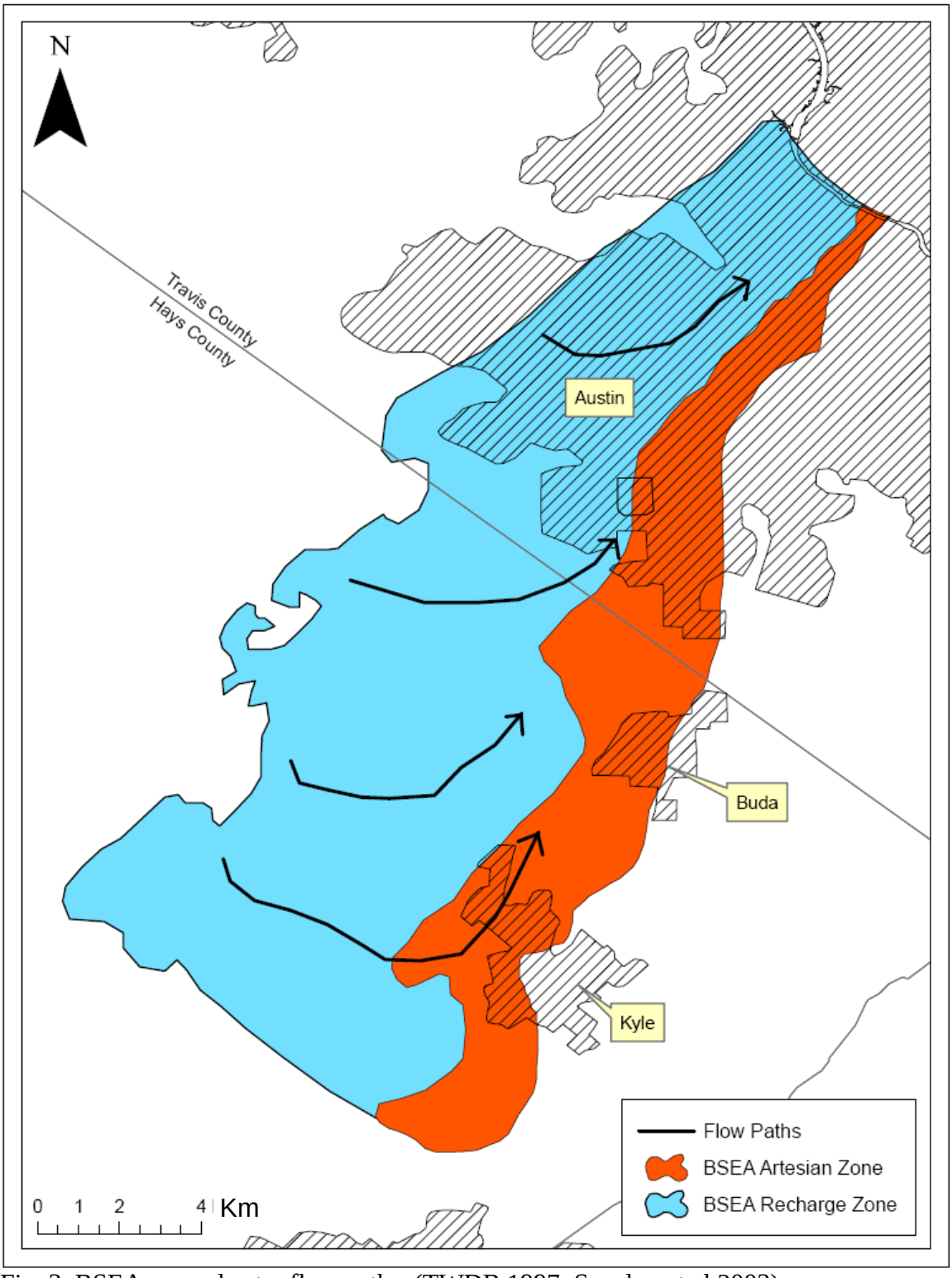

Fig. 3. BSEA groundwater flow paths. (TWDB 1997; Scanlon et al 2003)

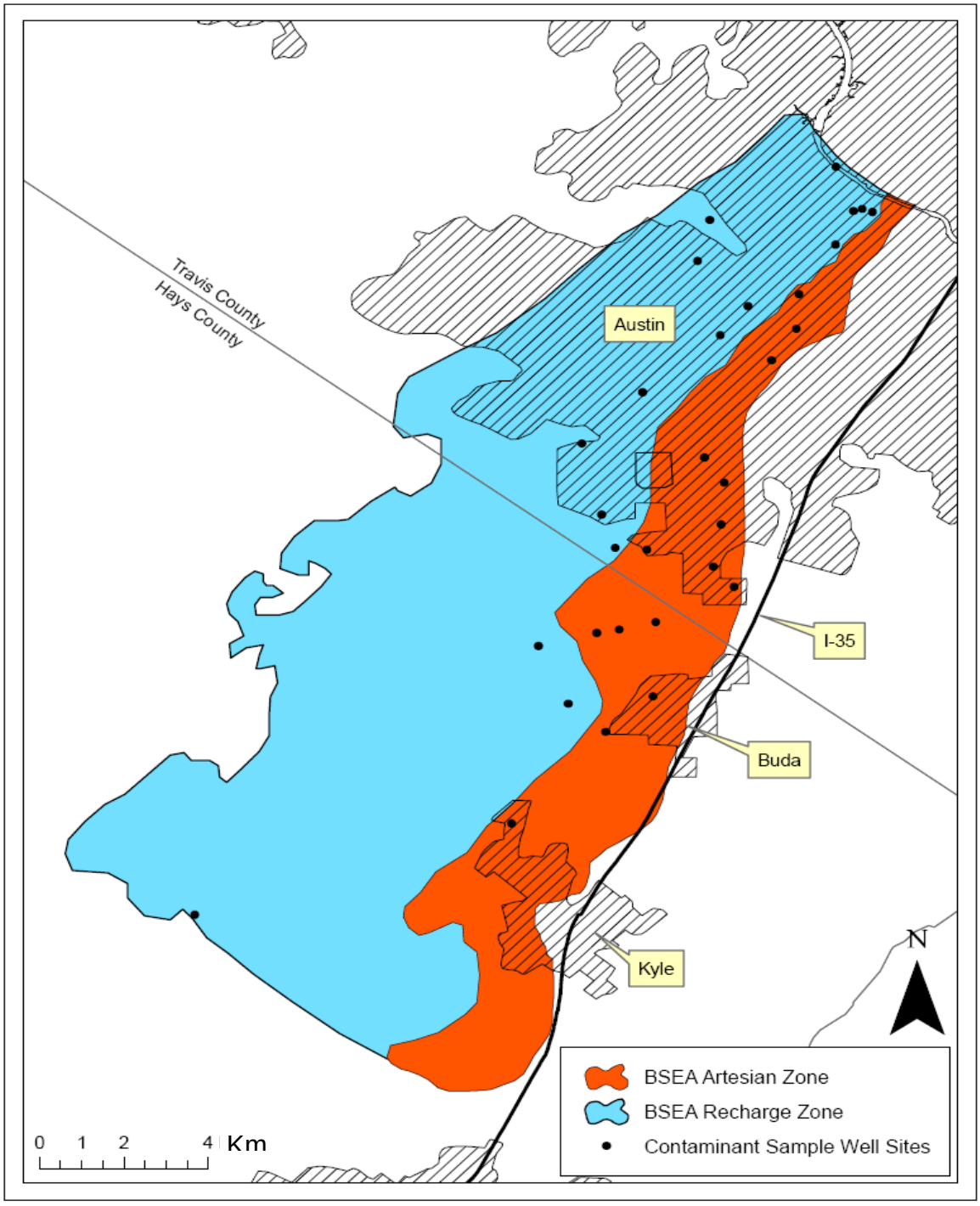

Fig. 4. Location of well sampling sites. (TWDB 1997; BSEACD 2001a)

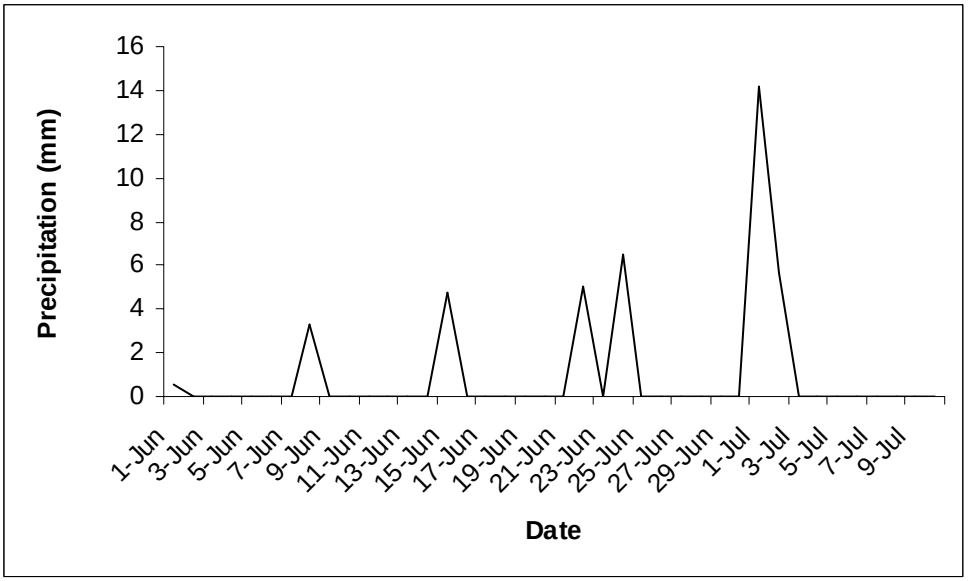

Fig. 5. Rainfall events across aquifer preceding and during well sampling, 2001. (Texas Weather Connection 2006)

Land Use- Five major types of land use will be examined: industrial, commercial, residential, agricultural and undeveloped. These categories have been determined from Land Use Land Cover (LULC) data obtained from USGS (1997). The LULC data represents land use over the Edwards Aquifer in 1997, based on the Level III Anderson classification scheme on a 1:24,000 scale. This is the most recent data available and assumes that no significant changes have taken place between this date and the date of groundwater sampling (2001). This is a limiting, yet unavoidable, factor which may influence the overall results.

Data Manipulation Techniques

The LULC and groundwater contaminant data are in GIS format for use with ArcGIS v. 9. The LULC data is comprised of polygons displaying land use in the categories defined above. The groundwater contaminant data is in point format, showing

the location of each well sampled for the contaminants across the aquifer. In order to determine which land use each well is located within to test for any differences in contaminant concentration between the three land use categories, each well will have a 1.6 km buffer placed around it. The land use is then determined by calculating the predominant land use to the southwest of the well within the buffer segment at an angle of 110º, thus accounting for the direction and movement of groundwater flow in a southwest to northeast direction (fig. 6). This is achieved in ArcGIS by recalculating the areas of each land use polygon within the buffer segment. This method does not take into account other land uses present in the vicinity of the well, or any localized groundwater flow which may influence the results. However, these assumptions are based on the success of this method used in previous research (Barton, Vowinkel, and Nawyn 1987; Grady and Weaver 1988; Eckhardt and Stackelberg 1995).

A buffer of 1.6 km is chosen based on the hydrogeology of the aquifer. Groundwater movement in Edwards Aquifer moves longitudinally through paths within the limestone causing a rapid dispersion of any contaminants contained within the water as the water flows away from the contaminant source (Bouwer 1978). This buffer distance should effectively account for any contaminants entering the groundwater immediately up-flow of each well where the sample is taken before the contaminant is dispersed.

Preliminary analysis of the land use data determines that the majority of the well sites would be classified as ‘undeveloped’. Therefore the undeveloped category will be dismissed for the statistical analysis that requires the designation of a land use category for each well site. The land use will be determined from the next greatest majority of land

use type present at each well site (table 2). This results in 3 wells classified as ‘industrial’ (I), 3 as ‘commercial’ (C), 7 as ‘agricultural’ (A), and 18 as ‘residential’ (R). The author recognizes this as a limiting factor to the study, with constraints placed on well selection through a lack of currently available well sites.

Table 2. Relative significance (%) of each land use for each contaminant sample well.

Well	Industrial	Commercial	Residential	Agricultural	Undeveloped	Land Use Class
1	0	0	50	0	50	R
2	2	5	8	15	70	A
3	0	3	12	38	46	A
4	0	1	10	15	74	A
5	0	7	4	4	84	C
6	0	0	75	15	5	R
7	0	1	18	4	70	R
8	10	4	1	30	54	A
9	4	1	33	11	51	R
10	0	3	26	13	57	R
11	0	11	5	0	84	C
12	0	0	25	0	75	R
13	0	1	19	16	64	R
14	0	1	15	0	84	R
15	12	20	3	0	65	C
16	3	5	16	16	59	A
17	3	9	66	0	22	R
18	0	3	33	1	63	R
19	10	17	62	0	11	R
20	14	0	7	10	70	I
21	10	0	7	2	82	I
22	0	0	40	50	10	A
23	0	4	27	20	49	R
24	0	0	30	65	5	A
25	3	11	64	0	22	R
26	4	11	29	0	56	R
27	9	10	69	0	13	R
28	38	10	28	0	24	I
29	5	10	44	0	18	R
30	8	11	42	1	16	R
31	8	4	60	0	28	R

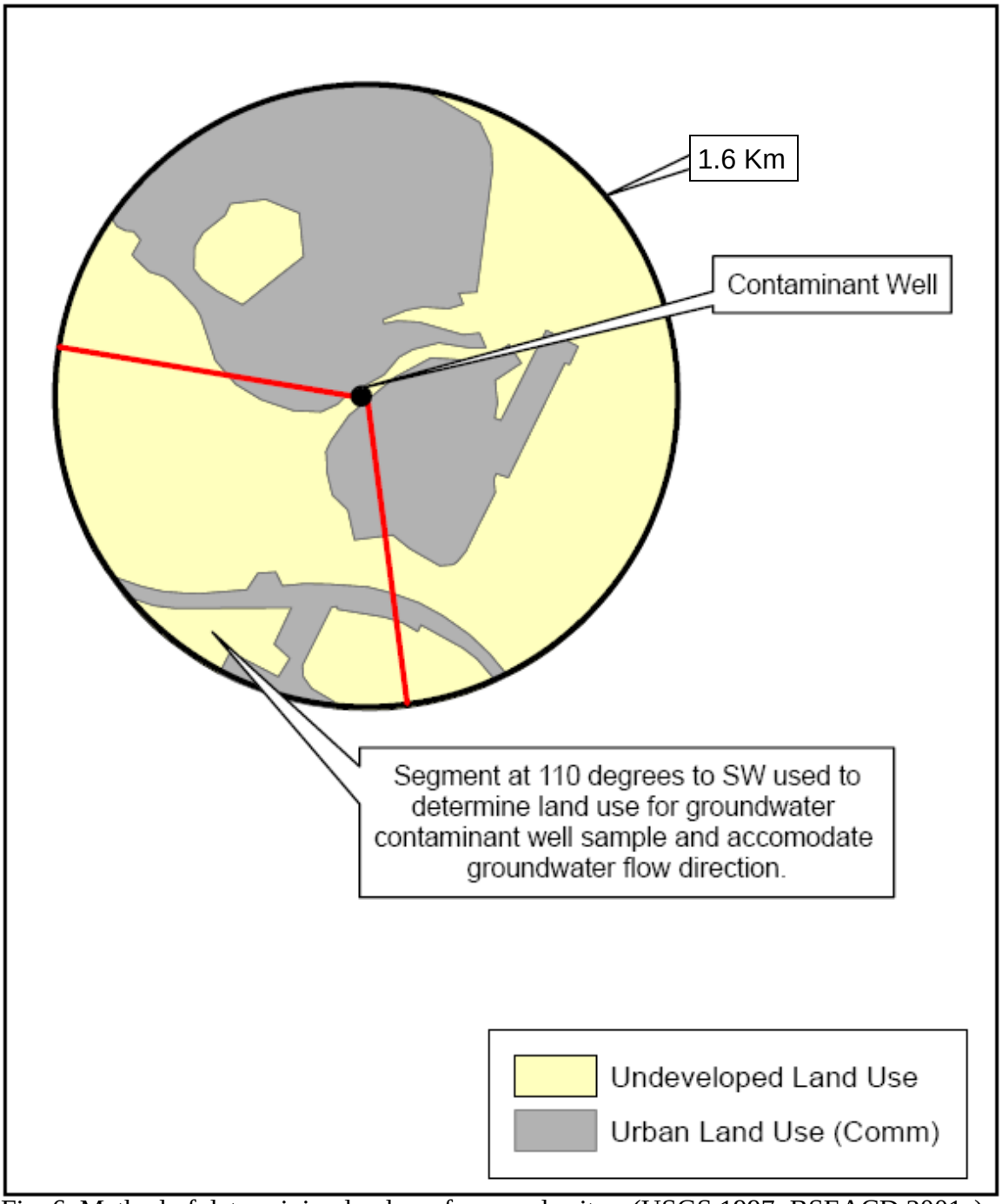

Fig. 6. Method of determining land use for sample sites. (USGS 1997; BSEACD 2001a)

Statistical Techniques

The contaminant data will be checked for spatial autocorrelation between each well by producing variograms in ArcGIS and removing any wells that are found to be significantly correlated spatially. Covariation between the 5 land use type variables and other possible non-land use variables including elevation, % geology at each site and distance to faulting will also be checked by running a correlation matrix. Geology and faulting data are available from BSEACD (fig. 7).

Following these data checks, descriptive statistics will provide the first basic analysis of the groundwater contaminant data. This will include the mean, median and quartiles of the contaminant concentrations to assess the variability and central tendency of each contaminant. Box plots will be generated to visually compare the descriptive statistics to determine if there are any differences in the concentration of the groundwater contaminants between each land use category.

Non-parametric statistics will be used to evaluate contaminant concentrations between the land use categories as the samples are small (n=31) and the contaminant data sets are generally not normally distributed. The Kruskal-Wallis test is a non-parametric method for comparing the mean rank of the total sample population to those of two or more independent groups, based on one factor (Pett 1997). This method is used to test the null hypothesis that there is no difference in any of the contaminant concentrations between the land use categories at the 95% significance level. As mentioned earlier, the undeveloped land use classification will be disregarded from this part of the analysis.

Regression analysis is a further technique which will be used to test whether the percentage of each land use type present at each well site can be used to predict the

concentration of each contaminant. This will include the undeveloped land use category as this part of the analysis does not require each well site to be designated a land use category.

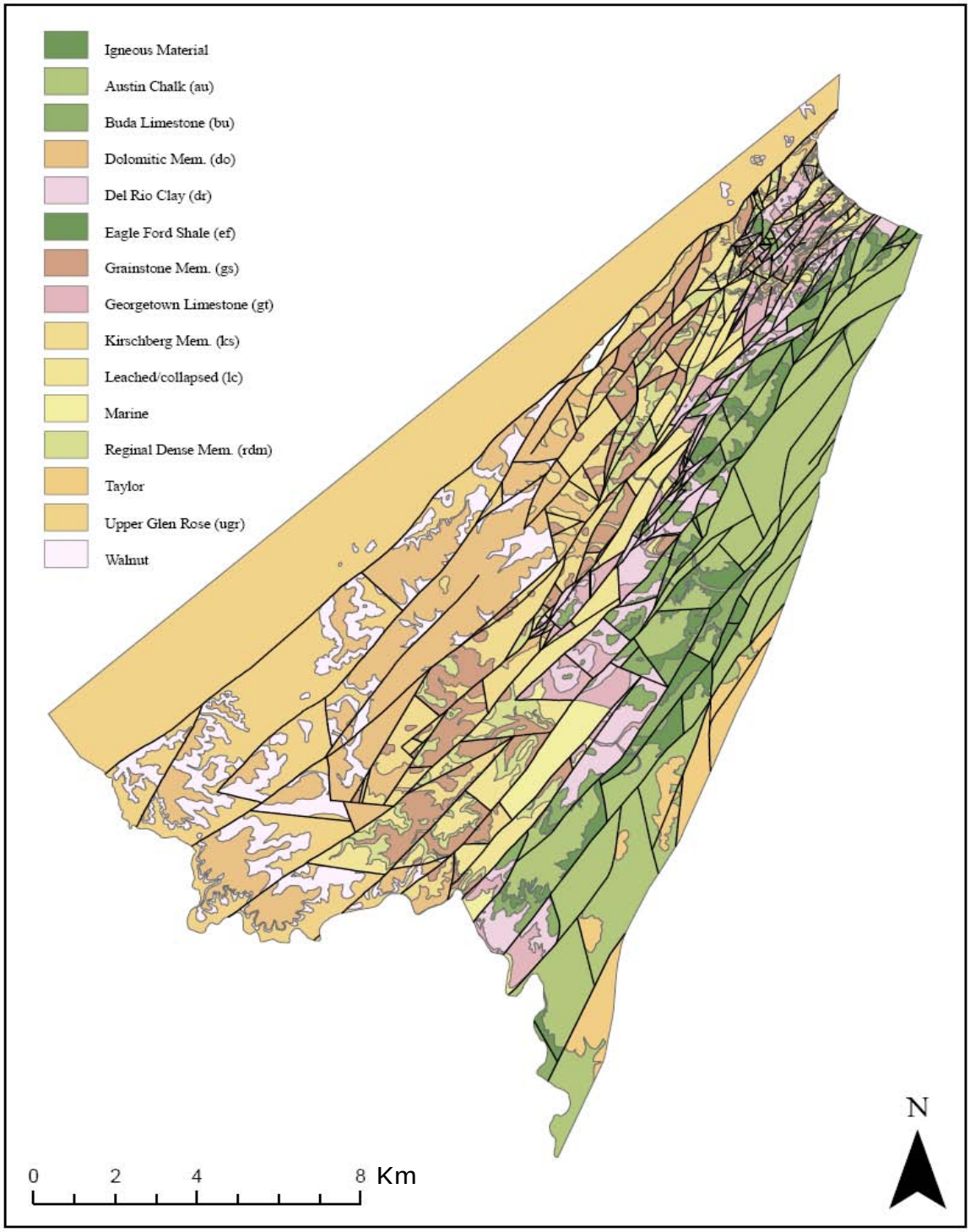

Fig. 7. Geology and faulting of Barton Springs segment. (BSEACD 2001c)

CHAPTER IV

RESULTS AND DISCUSSION

Spatial Autocorrelation

No spatial autocorrelation of the contaminant data between each well was found when the data was entered into ArcGIS. The data produced random patterns (figs. 8-12). Therefore no wells needed to be removed from the analysis due to spatial correlation.

Fig. 8. Semi-variogram for Bromofluorobenzene (top) and DB (bottom).

Fig. 9. Semi-variogram for Decachlorobiphenyl (top), Dichlorobenzene (middle), and Fluorobiphenyl (bottom).

Fig. 10. Semi-variogram for Fluorophenol (top), Nitrate (middle), and Nitrobenzene (bottom).

Fig. 11. Semi-variogram for Phenol (top), Phorate (middle), and Terphenyl (bottom).

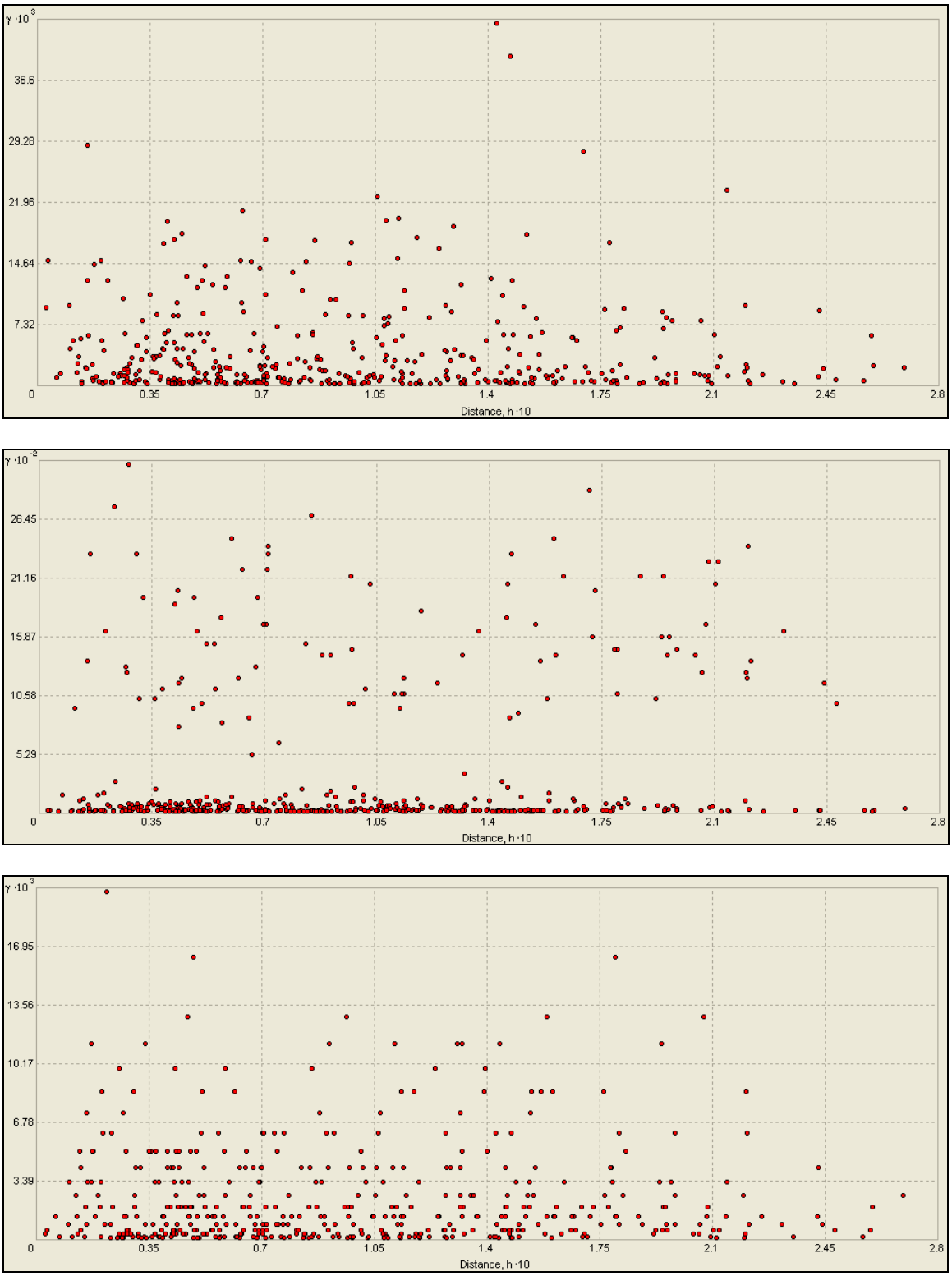

Fig. 12. Semi-variogram for Tetrachloro-m-xylene (top), Tribromophenol (middle), and Triphenyl Phosphate (bottom).

Covariation Test

A correlation matrix was produced (table 3) using Minitab 15 statistical software to check for any covariation between the five predictor land use variables and any other non-land use predictor variables that could possibly affect groundwater contamination levels (elevation, distance to faulting, and percentage area of each rock type present within the Edwards Aquifer). The matrix produced 31 covariations between the variables. However closer analysis renders most of these covariations as coincidental. Most of the covariation between the rock types are simply because they were not even present at the majority of the well sites bar one or two occurrences.

The two covariations of major significance in this study area are those between industrial and commercial land use areas and undeveloped land use areas and elevation. Here it can be accepted that industrial and commercial land uses will tend to group together, especially within urban areas like Austin. Higher elevations tend to be less developed. The author therefore recognizes these two covariations within the study, although generally there are no significant covariations between the percentage of land use areas and any of the other non-land use variables checked in this study.

Descriptive Statistics

Descriptive statistics for each contaminant by land use are shown in table 4 and figures 13-17 (histograms) and figures 18-20 (boxplots). These further verify that the contaminant concentrations were not normally distributed by land use type. Variation in contaminant concentrations between land uses are similar for Bromofluorobenzene, Dichlorobenzene, Fluorophenol, and Phenol when not accounting for possible outliers.

Table 3. Correlation matrix of predictor variables. All variables measured as %, except elevation and distance to faulting (meters). Geology represented as follows; DO= Dolomitic Member; GS= Grainstone Member; KS= Kirschberg Member; LC= Leached/collapsed; RDM= Reginal Dense Member; UGR= Upper Glen Rose; AU= Austin Chalk; BU= Buda Limestone; DR= Del Rio Clay; EF= Eagle Ford Shale; GT= Georgetown Limestone. * indicates significant at 95% level.

	Ind	Com	Res	Agri	Undev	Elev	Fault Dist.	DO	GS	KS	LC	RDM	UGR	AU	BU	DR	EF	gt
Ind	1.00																	
Com	.38*																	
Res	-0.01	0.16	1.00															
Agri	-0.25	-.43*	-0.18	1.00														
Undev	-0.21	-0.23	-.79*	-0.26	1.00													
Elev	-0.12	-0.25	-.59*	0.07	.57*	1.00												
Fault Dist.	-0.17	-0.21	-0.08	0.14	0.09	.39*	1.00											
DO	-0.16	-0.23	-0.10	-0.17	0.30	0.35	0.27	1.00										
GS	-0.09	0.21	0.00	-0.30	0.18	-0.11	-0.06	0.09	1.00									
KS	-0.10	0.02	-0.14	-0.22	0.30	-0.03	0.00	0.31	.85*	1.00								
LC	-0.11	.50*	-0.06	-.37*	0.22	-0.17	-0.32	-0.04	0.34	0.22	1.00							
RDM	-0.01	.49*	0.03	-0.34	0.09	-0.14	-0.11	-0.06	.76*	.53*	.62*	1.00						
UGR	-0.13	-0.20	-0.05	-0.14	0.22	.47*	0.31	.91*	-0.05	0.01	-0.11	-0.09	1.00					
AU	0.06	-0.29	0.19	0.19	-0.30	-0.06	0.18	-0.25	-.38*	-0.32	-.46*	-.41*	-0.20	1.00				
BU	0.15	-0.08	0.07	0.35	-0.27	-0.02	-0.05	-0.24	-.39*	-0.32	-.37*	-.41*	-0.19	-0.05	1.00			
DR	-0.05	-0.02	-0.29	0.04	0.26	0.20	-0.18	-0.24	-0.25	-0.27	-0.14	-0.33	-0.19	-0.32	0.22	1.00		
EF	0.15	-0.17	0.11	.46*	-.42*	-0.15	0.03	-0.23	-.35*	-0.30	-.44*	-.37*	-0.18	.40*	0.33	-.36*	1.00	
gt	-0.07	0.13	0.06	-0.07	-0.04	-0.14	-0.04	-0.15	-0.07	-0.16	0.20	0.01	-0.13	-.38*	-0.08	.46*	-.36*	1.00

For other contaminant concentrations there is a difference in variation between land uses. In particular, Nitrate has a much reduced variation across industrial land uses compared to other land use types. Tribromophenol has a much wider variance in industrial areas; Terphenyl has a much smaller spread of concentrations in industrial areas, and Nitrobenzene also has a reduced variation in concentration in industrial areas. The standard deviation of contaminant concentrations illustrates that the concentrations are more widespread for Fluorobiphenyl in industrial and residential areas, Fluorophenol in agricultural areas, Tribromophenol in industrial areas, Nitrobenzene in commercial and residential areas, Phenol in agricultural areas, DB in commercial and industrial areas, and Terphenyl in residential areas (table 4). The outliers present for DB in residential areas and Fluorophenol and Phenol in agricultural areas are likely a result of the rainfall events that occurred immediately before sampling area wells, which would temporarily increase the groundwater flow within the aquifer.

Maximum contaminant concentrations for Nitrate (3.17 mg/L) and Fluorophenol (142 µg/L) were considerably larger in residential areas, and also for Tribromophenol in industrial areas. Mean concentrations of Fluorophenol (109.7 µg/L) and Fluorobiphenyl (57.23 µg/L) were notably lower in agricultural and industrial areas respectively. Mean concentrations of Phenol (154 µg/L) and DB (9.31 µg/L) were higher in industrial and agricultural land uses respectively. Mean concentrations of Terphenyl were higher in both agricultural (80.06 µg/L) and industrial (79.37 µg/L) land uses.

It should also be noted that none of the contaminants listed in the 1974 SDWA exceeded MCL’s (DB, Dichlorobenzene, Nitrate, and Tetrachloro-m-xylene; table 1).

Table 4. Descriptive statistics for groundwater contaminants by land use.

Contaminant	Land Use	Mean	Median	Minimum	Maximum	Q1	Q3	IQR	StDev
Bromofluorobenzene	A	4.90	4.80	4.70	5.20	4.70	5.20	0.50	0.22
	C	5.03	4.90	4.90	5.30	4.90	5.30	0.40	0.23
	I	4.97	4.90	4.80	5.20	4.80	5.20	0.40	0.21
	R	5.03	5.10	4.60	5.30	4.78	5.30	0.53	0.26
DB	A	9.31	10.00	5.40	11.00	9.30	10.00	0.70	1.81
	C	6.67	5.40	3.60	11.00	3.60	11.00	7.40	3.86
	I	7.27	5.10	3.70	13.00	3.70	13.00	9.30	5.01
	R	5.09	4.85	3.50	11.00	3.70	5.33	1.63	2.01
Decachlorobiphenyl	A	0.60	0.59	0.55	0.63	0.58	0.63	0.05	0.03
	C	0.60	0.61	0.56	0.62	0.56	0.62	0.06	0.03
	I	0.55	0.52	0.50	0.63	0.50	0.63	0.14	0.07
	R	0.57	0.58	0.46	0.75	0.51	0.61	0.09	0.07
Dichlorobenzene	A	4.90	4.80	4.60	5.30	4.70	5.30	0.60	0.28
	C	5.10	5.10	4.80	5.40	4.80	5.40	0.60	0.30
	I	4.93	4.80	4.70	5.30	4.70	5.30	0.60	0.32
	R	5.04	5.15	4.40	5.50	4.78	5.30	0.53	0.32
Fluorobiphenyl	A	65.47	65.40	59.70	69.40	63.00	69.00	6.00	3.42
	C	66.57	68.80	61.30	69.60	61.30	69.60	8.30	4.58
	I	57.23	52.70	49.50	69.50	49.50	69.50	20.00	10.74
	R	61.98	63.35	47.50	73.40	54.10	69.00	14.90	8.45
Fluorophenol	A	109.70	121.00	32.10	134.00	110.00	128.00	18.00	35.20
	C	115.33	118.00	102.00	126.00	102.00	126.00	24.00	12.22
	I	115.67	115.00	108.00	124.00	108.00	124.00	16.00	8.02
	R	113.40	111.50	83.00	142.00	103.00	126.00	23.00	14.31
Nitrate	A	1.07	1.09	0.07	1.85	0.74	1.52	0.78	0.57
	C	1.08	0.94	0.26	2.05	0.26	2.05	1.79	0.90
	I	1.18	1.25	0.99	1.29	0.99	1.29	0.30	0.16
	R	1.27	1.22	0.00	3.17	0.74	1.63	0.88	0.82
Nitrobenzene	A	70.46	71.40	67.30	74.00	67.70	72.00	4.30	2.44
	C	66.83	69.50	61.40	69.60	61.40	69.60	8.20	4.71
	I	71.20	71.60	70.00	72.00	70.00	72.00	2.00	1.06
	R	66.49	66.80	56.00	72.20	64.28	70.40	6.13	4.39
Phenol	A	125.80	139.00	41.40	145.00	129.00	145.00	16.00	37.60
	C	131.67	137.00	118.00	140.00	118.00	140.00	22.00	11.93
	I	154.00	155.00	150.00	157.00	150.00	157.00	7.00	3.61
	R	132.28	135.00	106.00	160.00	123.75	140.25	16.50	12.20
Phorate	A	0.33	0.36	0.27	0.37	0.29	0.37	0.08	0.04
	C	0.22	0.21	0.15	0.30	0.15	0.30	0.15	0.08
	I	0.27	0.23	0.21	0.38	0.21	0.38	0.17	0.09
	R	0.34	0.38	0.17	0.45	0.29	0.41	0.12	0.08
Terphenyl	A	80.06	80.10	78.50	81.60	79.40	80.90	1.50	1.05
	C	75.80	75.70	73.20	78.50	73.20	78.50	5.30	2.65
	I	79.37	79.30	78.70	80.10	78.70	80.10	1.40	0.70
	R	76.19	75.60	69.40	83.20	73.78	79.30	5.53	4.01
Tetrachloro-m-xylene	A	0.42	0.41	0.39	0.45	0.41	0.44	0.03	0.02
	C	0.45	0.45	0.40	0.49	0.40	0.49	0.09	0.05
	I	0.44	0.39	0.37	0.57	0.37	0.57	0.20	0.11
	R	0.43	0.42	0.28	0.56	0.38	0.47	0.09	0.07
Tribromophenol	A	93.21	94.20	85.30	97.80	90.20	97.70	7.50	4.62
	C	95.57	94.90	87.80	104.00	87.80	104.00	16.20	8.12
	I	137.00	153.00	93.90	164.00	93.90	164.00	70.10	37.70
	R	105.21	99.75	95.10	148.00	97.00	103.95	6.95	15.23
Triphenyl Phosphate	A	0.50	0.50	0.45	0.55	0.46	0.54	0.08	0.04
	C	0.56	0.56	0.53	0.58	0.53	0.58	0.05	0.03
	I	0.49	0.49	0.47	0.51	0.47	0.51	0.04	0.02
	R	0.47	0.45	0.40	0.60	0.45	0.51	0.06	0.05

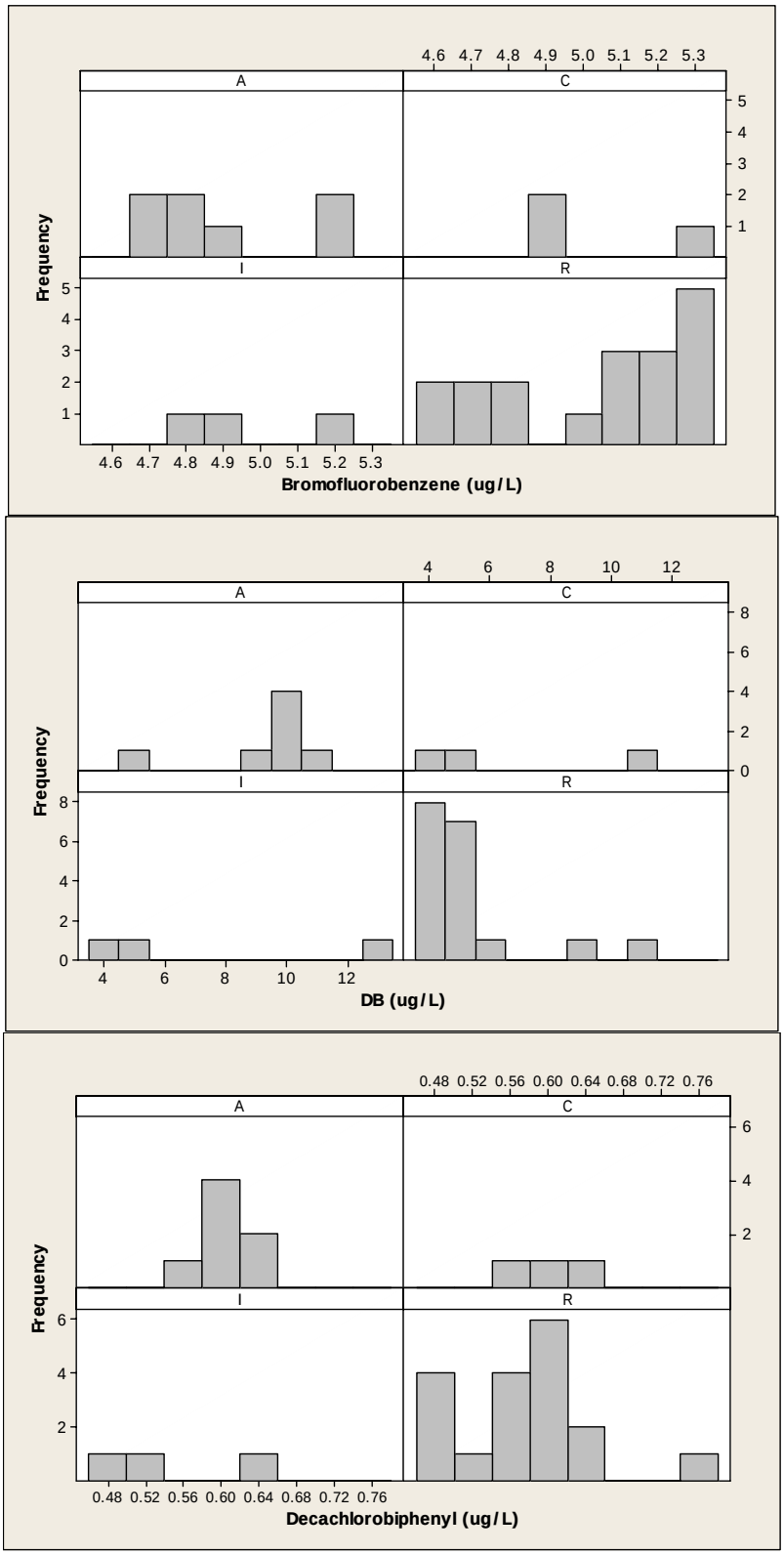

Fig. 13. Frequency histograms by land use for Bromofluorobenzene (top), DB (middle), and Decachlorobiphenyl (bottom).

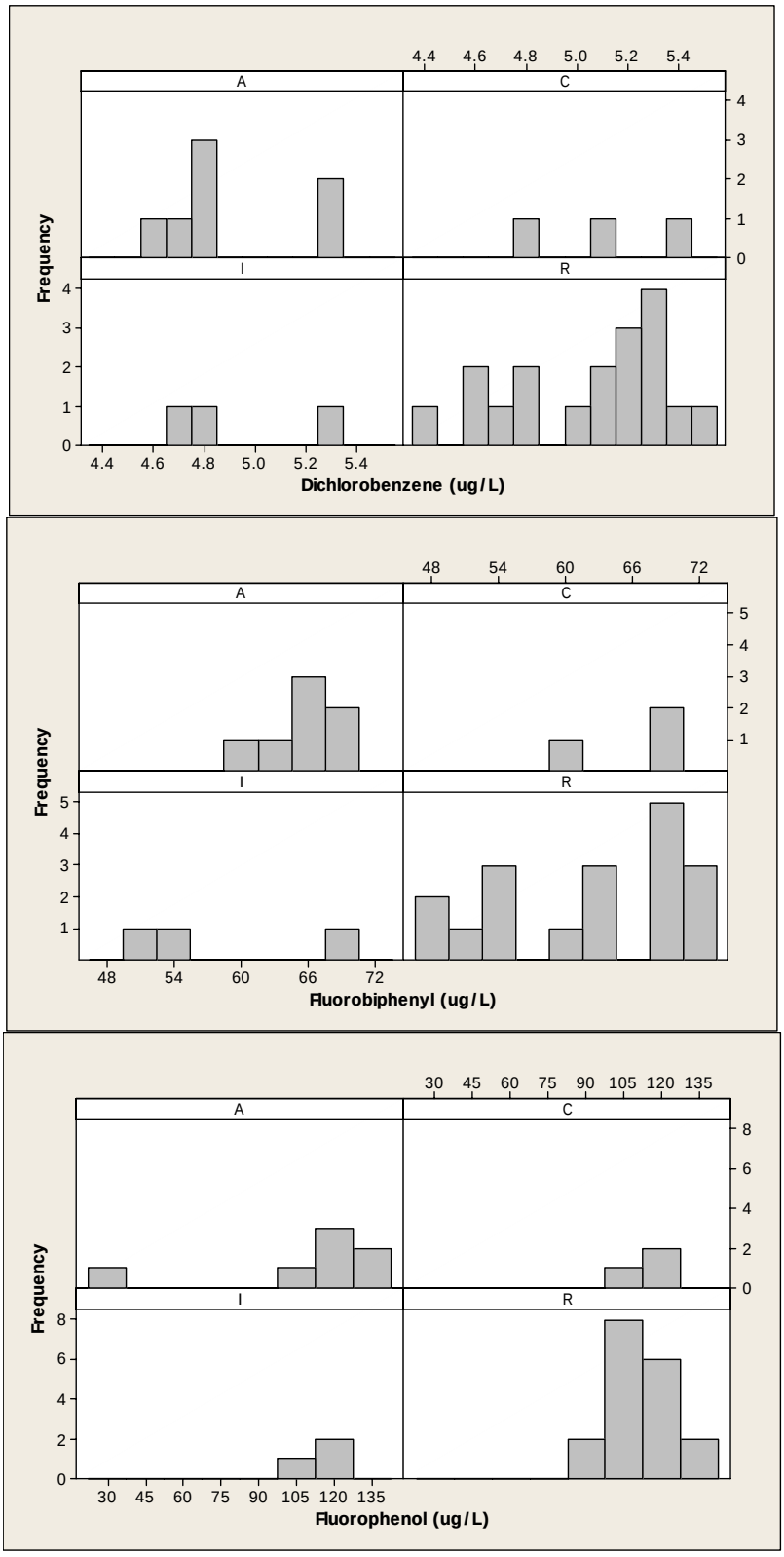

Fig. 14. Frequency histograms by land use for Dichlorobenzene (top), Fluorobiphenyl (middle), and Fluorophenol (bottom).

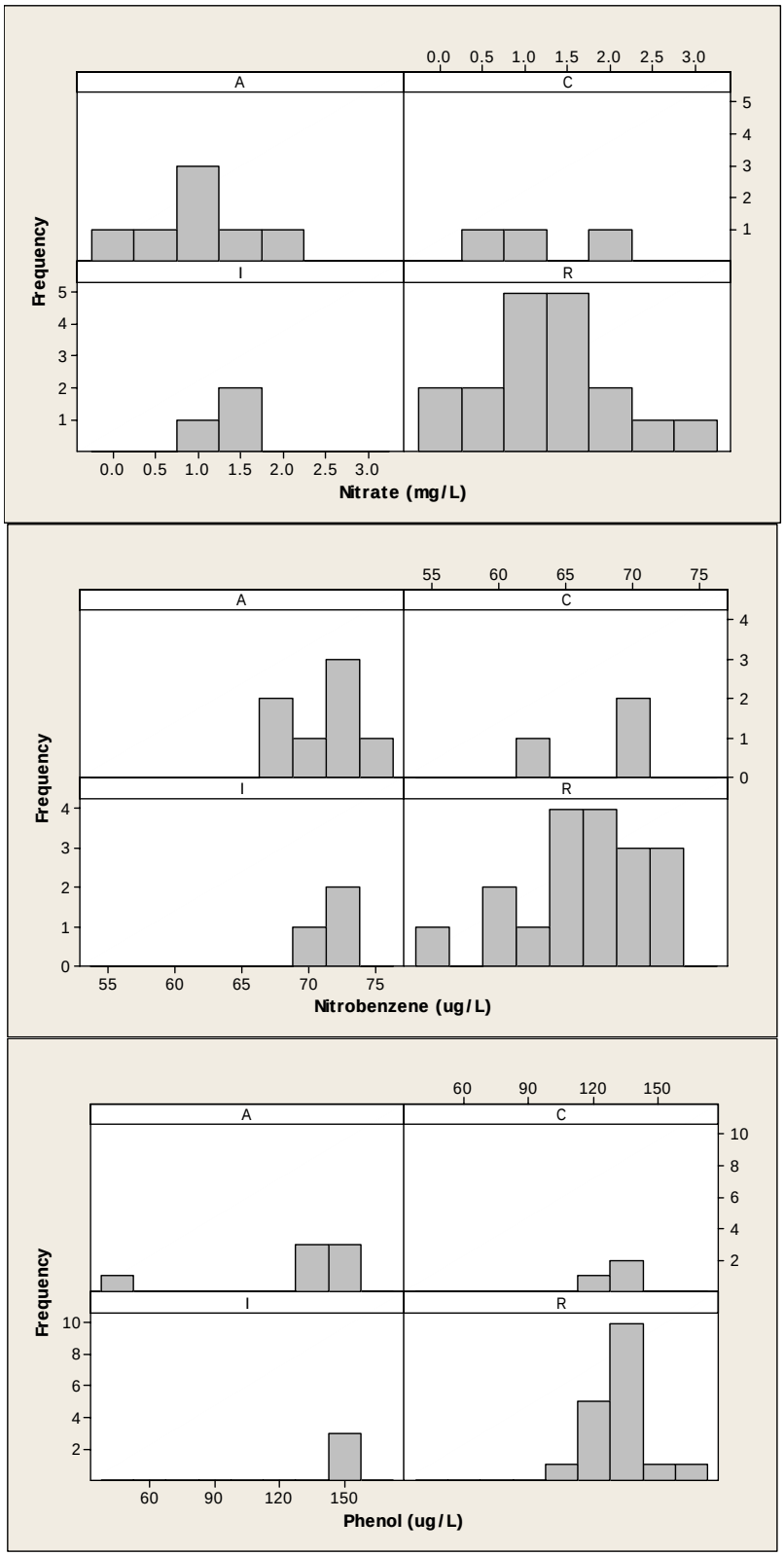

Fig. 15. Frequency histograms by land use for Nitrate (top), Nitrobenzene (middle), and Phenol (bottom).

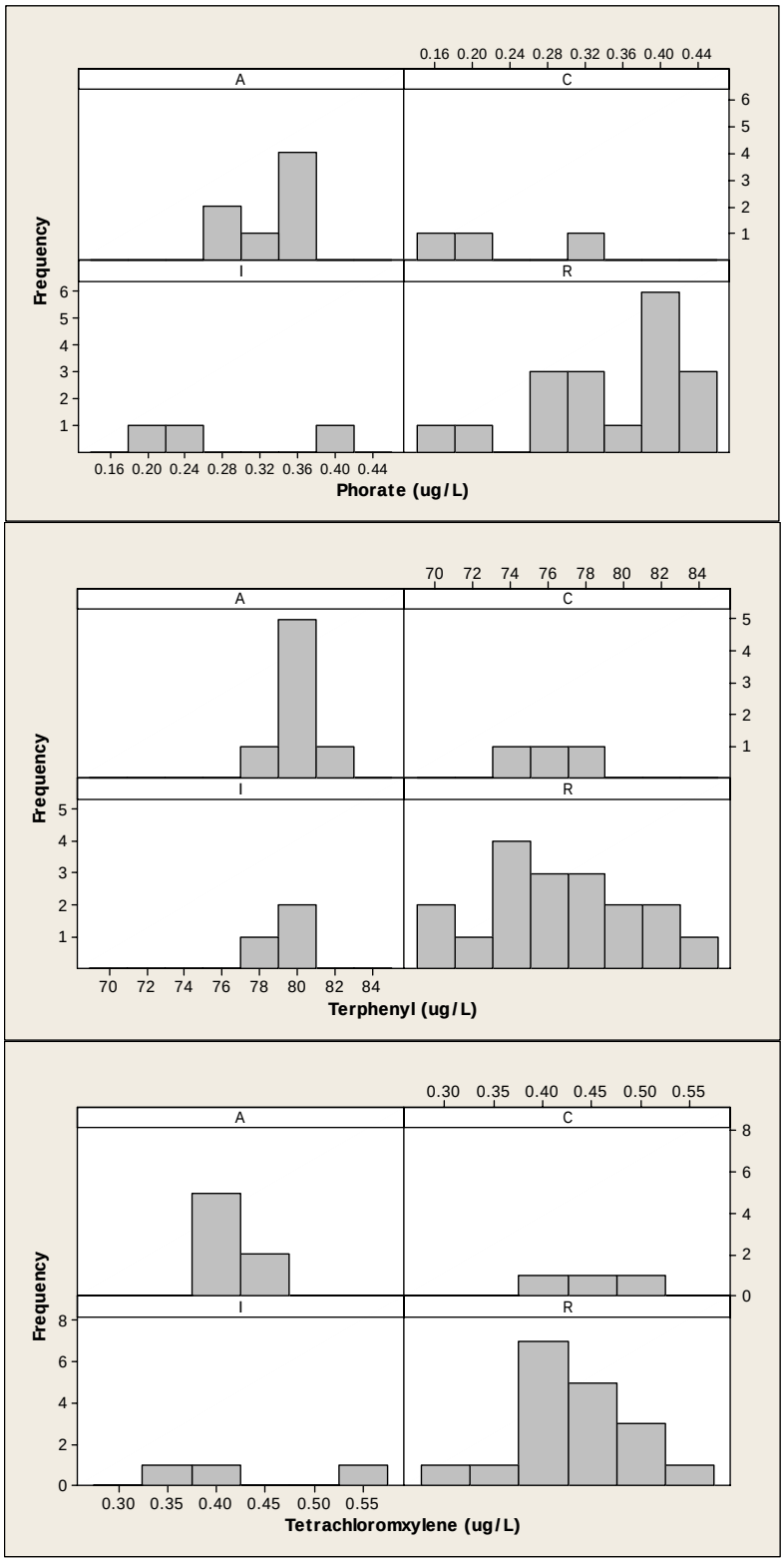

Fig. 16. Frequency histograms by land use for Phorate (top), Terphenyl (middle), and Tetrachloro-m-xylene (bottom).

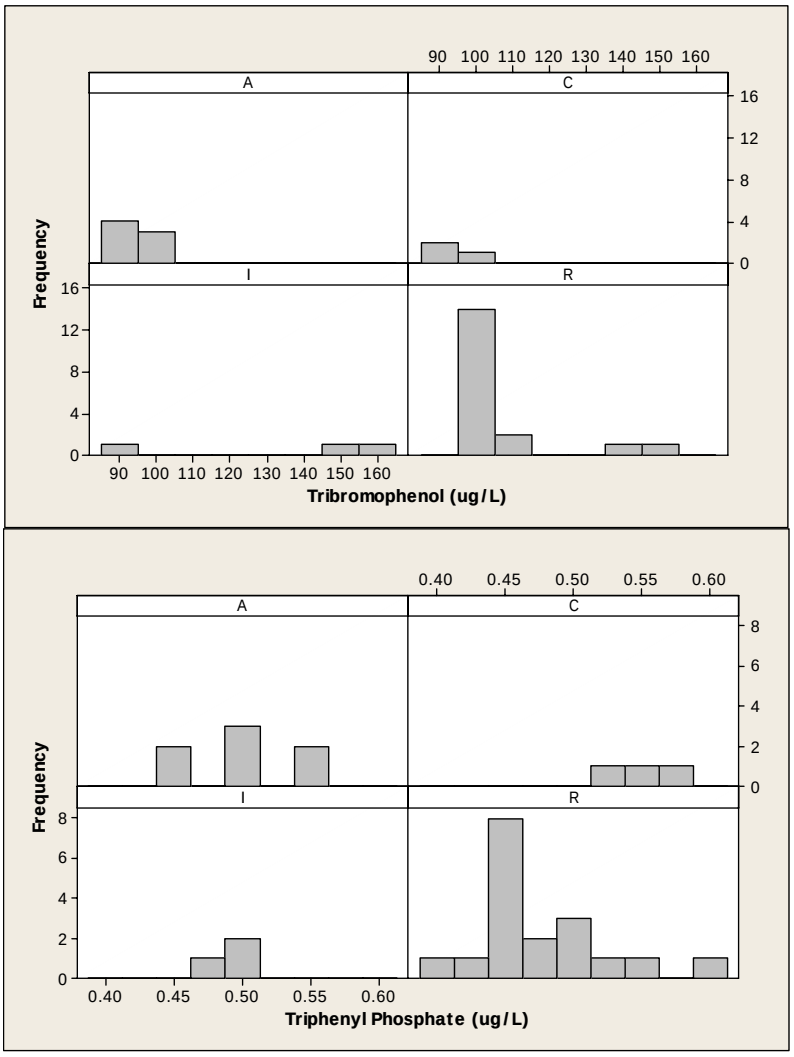

Fig. 17. Frequency histograms by land use for Tribromophenol (top), and Triphenyl Phosphate (bottom).

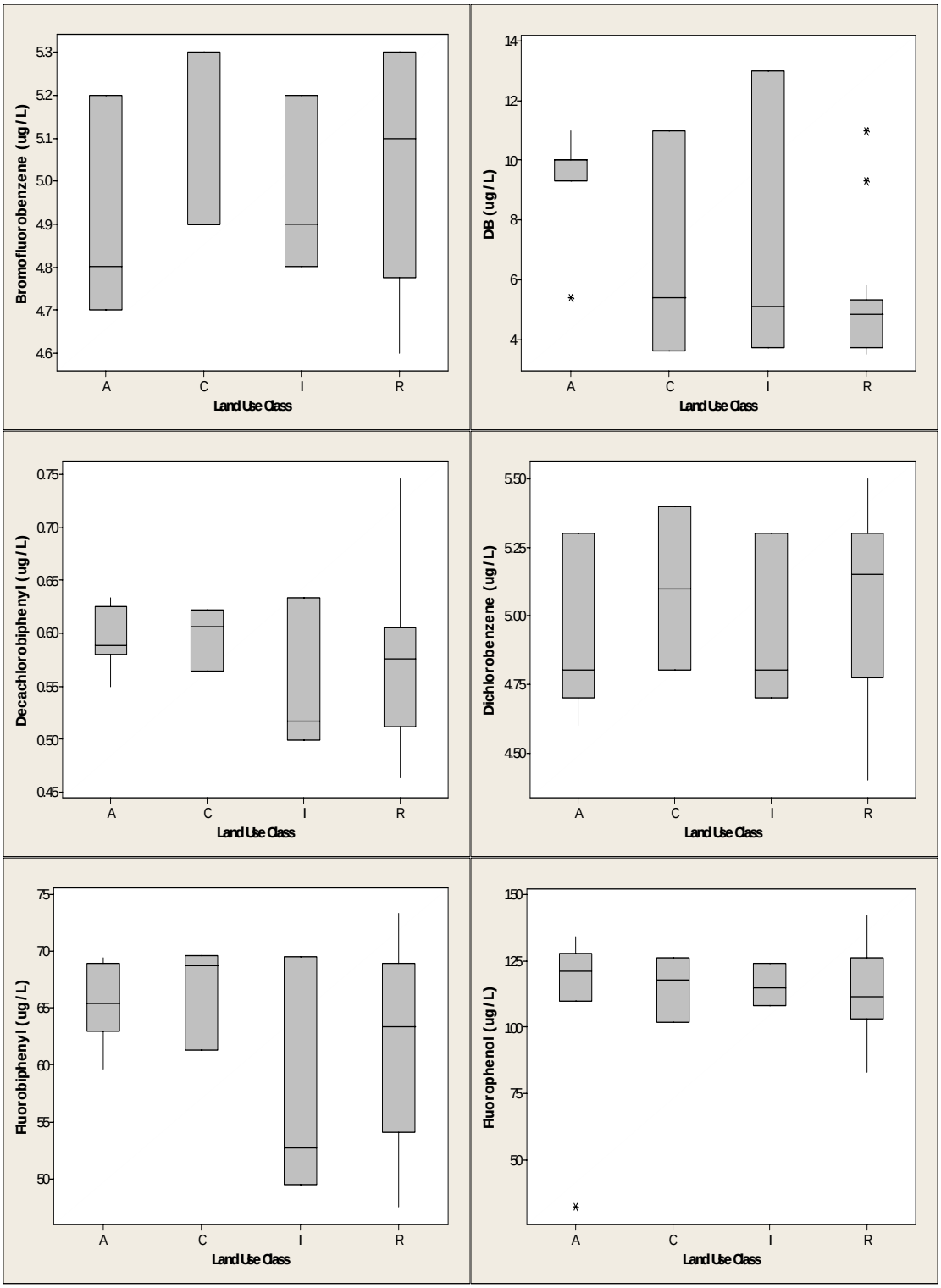

Fig. 18. Boxplots by land use for Bromofluorobenzene, DB, Decachlorobiphenyl, Dichlorobenzene, Fluorobiphenyl, and Fluorophenol.

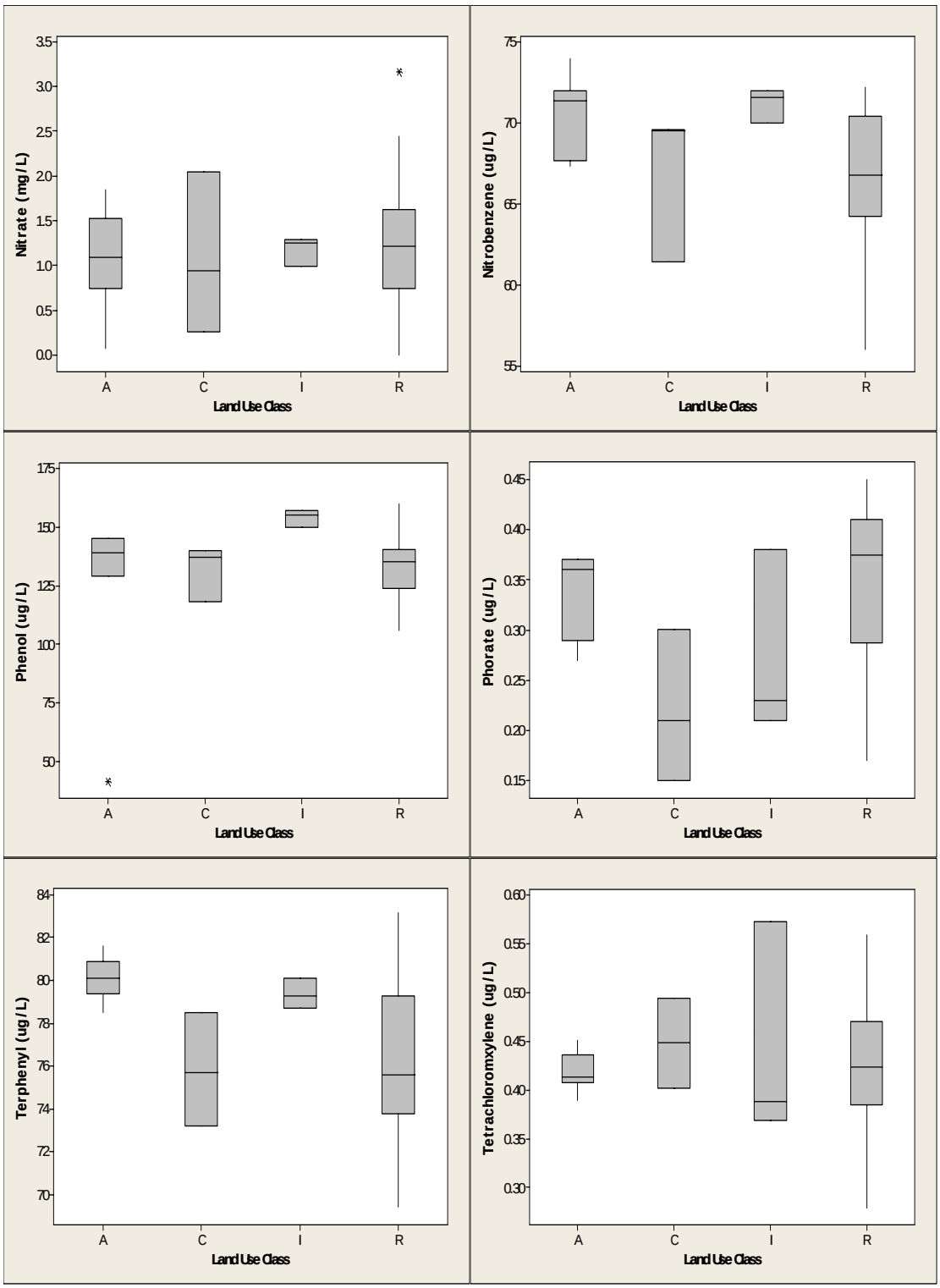

Fig. 19. Boxplots by land use for Nitrate, Nitrobenzene, Phenol, Phorate, Terphenyl, and Tetrachloro-m-xylene.

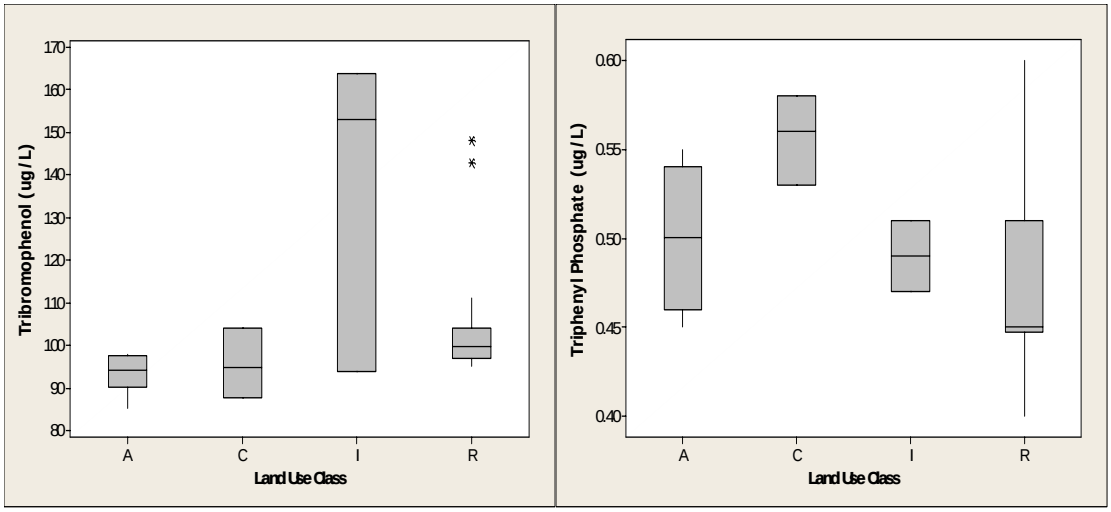

Fig. 20. Boxplots by land use for Tribromophenol and Triphenyl Phosphate.

Kruskall-Wallis Land Use Comparison

Kruskall-Wallis analysis determines that 6 of the 14 contaminants have significant differences in median concentrations by land use type (table 5). DB has a significantly higher ($p=0.024$) median concentration in agricultural areas. DB is an ingredient used in many types of agricultural herbicides, thus these results reflect the spatial pattern of this usage. Agricultural areas are associated with herbicide use, portions of which will leach into the groundwater. Herbicides are also used in residential areas, although these tend to be different in make-up and strength, explaining the lower median concentration of DB registered in residential areas.

Of all the land use types monitored in this study, industrial land uses accounted for the most significant median contaminant concentration differences among the groundwater contaminants recorded. Median concentrations in Nitrobenzene, Phenol and Tribromophenol were all significantly greater ($p<0.05$) in industrial areas. All three of

these contaminants are commonly used in industrial processes and manufacturing household products (table 1). Their presence in the groundwater located adjacent to these

Table 5. Kruskall-Wallis analysis of groundwater contaminants by land use. * indicates significant at 95%.

Contaminant	Land Use	Median	Ave. Rank	p
Bromofluorobenzene	Industrial	4.9	15	0.615
	Commercial	4.9	18.5	
	Residential	5.1	17.2	
	Agricultural	4.8	12.2	
DB	Industrial	5.1	17	0.024*
	Commercial	5.4	17	
	Residential	4.85	12.3	
	Agricultural	10	24.6	
Decachlorobiphenyl	Industrial	0.517	12.8	0.481
	Commercial	0.606	19.7	
	Residential	0.5755	14.5	
	Agricultural	0.588	19.6	
Dichlorobenzene	Industrial	4.8	14	0.701
	Commercial	5.1	19.2	
	Residential	5.15	16.9	
	Agricultural	4.8	13.1	
Fluorobiphenyl	Industrial	52.7	11.3	0.626
	Commercial	68.8	20.3	
	Residential	63.35	15.4	
	Agricultural	65.4	17.6	
Fluorophenol	Industrial	115	15.5	0.8
	Commercial	118	15.7	
	Residential	111.5	15	
	Agricultural	121	19	
Nitrate	Industrial	1.25	16.7	0.955
	Commercial	0.94	14	
	Residential	1.22	16.6	
	Agricultural	1.09	15	
Nitrobenzene	Industrial	71.6	24.8	0.042*
	Commercial	69.5	13.7	
	Residential	66.8	12.7	
	Agricultural	71.4	21.7	
Phenol	Industrial	155	29	0.046*
	Commercial	137	13.7	
	Residential	135	13.5	
	Agricultural	139	17.9	
Phorate	Industrial	0.23	10.8	0.101
	Commercial	0.21	6.2	
	Residential	0.375	18.8	
	Agricultural	0.36	15.3	
Terphenyl	Industrial	79.3	20.8	0.033*
	Commercial	75.7	10.8	
	Residential	75.6	13.1	
	Agricultural	80.1	23.7	
Tetrachloromxylene	Industrial	0.388	14.3	0.872
	Commercial	0.448	20	
	Residential	0.4235	15.7	
	Agricultural	0.413	15.8	
Tribromophenol	Industrial	153	22	0.02*
	Commercial	94.9	11.3	
	Residential	99.75	19	
	Agricultural	94.2	7.7	
Triphenyl Phosphate	Industrial	0.49	17.3	0.048*
	Commercial	0.56	27.8	
	Residential	0.45	12.9	
	Agricultural	0.5	18.4	

industrial areas strongly suggests that some of these contaminants are leaking into the groundwater during the process of product manufacture. This is a major concern for drinking water regarding the BSEA which is heavily relied on by the city of Austin and smaller surrounding towns and villages.

Other significant differences in median contaminant concentrations by land use include Terphenyl, which exhibits higher median concentrations for industrial and agricultural areas; and Triphenyl Phosphate which recorded higher median concentrations across industrial and commercial land uses. Terphenyl is used in the manufacturing of agricultural pesticides, and so it is unexpected to be higher in concentration in predominantly industrial areas, although agricultural land use was present in 2 of the 3 buffers classified as predominantly industrial. The same could be said for Triphenyl Phosphate, another substance used in many industrial manufacturing processes, as commercial land uses will tend to cluster with industrial areas in urban areas, thus accounting for the higher median concentrations for both industrial and commercial sectors.

Regression Analysis

Regression analysis was used to determine whether the area of each land use type can be used to predict the concentration of each groundwater contaminant. The results are extremely wide ranging and far from simple (table 6). Linear and quadratic regression models were run for each contaminant concentration by land use area taken as a percentage of that land use present in each well buffer segment (fig. 6). First not all groundwater contaminants displayed significant regression in terms of land use area.

Table 6. Regression analysis for each contaminant by percentage land use type area. * indicates significant at 95%.

			Linear		Quadratic	
Contaminant	Land Use	p	R-sq (%)	Adj. R-sq (%)	R-sq (%)	Adj. R-sq (%)
Bromofluorobenzene	I	0.156	6.8	3.6	8.9	2.4
	C	0.091	9.5	6.4	11.7	5.4
	R	0.312	3.5	0.2	8	1.5
	A	0.133	7.6	4.4	7.7	1.1
	U	0.325	3.3	0	3.8	0
DB	I	0.288	3.9	0.6	4.2	0
	C	0.029*	15.4	12.5	16.3	10
	R	0.007*	22.8	20.1	23.6	18.1
	A	0*	41.3	39.3	48.2	44.5
	U	0.292	3.8	0.5	4.4	0
Decachlorobiphenyl	I	0.723	0.4	0	3.7	0
	C	0.577	1.1	0	2.4	0
	R	0.693	0.5	0	0.8	0
	A	0.979	0	0	2.7	0
	U	0.799	0.2	0	9.1	2.6
Dichlorobenzene	I	0.172	6.3	3.1	7.2	0.5
	C	0.070	10.9	7.8	13.8	7.6
	R	0.490	1.7	0	4.4	0
	A	0.170	6.2	2.9	6.3	0
	U	0.422	2.2	0	3.9	0
Fluorobiphenyl	I	0.992	0	0	4.8	0
	C	0.378	2.7	0	25.8	25
	R	0.731	0.4	0	2.6	0
	A	0.562	1.2	0	1.5	0
	U	0.570	1.1	0	1.4	0
Fluorophenol	I	0.840	0.1	0	0.4	0
	C	0.750	0.4	0	20.8	15.1
	R	0.360	2.9	0	3.8	0
	A	0.029*	15.4	12.5	49.4	45.8
	U	0.075	10.5	7.4	23.8	18.3
Nitrate	I	0.695	0.5	0	5.2	0
	C	0.516	0.5	0	2.8	0
	R	0.619	0.9	0	0.9	0
	A	0.650	0.7	0	2	0
	U	0.644	0.7	0	6.2	0
Nitrobenzene	I	0.904	0.1	0	8.3	1.7
	C	0.008*	22.1	19.4	29.9	23.9
	R	0.080	10.2	7.1	8.4	1.9
	A	0.141	7.3	4.1	12.2	5.9
	U	0.222	5.1	1.8	5.2	0

Table 6. (continued). * indicates significant at 95%.

			Linear		Quadratic	
Contaminant	Land Use	p	R-sq (%)	Adj. R-sq (%)	R-sq (%)	Adj. R-sq (%)
Phenol	I	0.151	7	3.8	4.1	0
	C	0.736	0.4	0	10.7	4.3
	R	0.385	2.6	0	3	0
	A	0.003*	27.1	24.6	53.5	50.2
	U	0.059	11.7	8.7	22.2	16.7
Phorate	I	0.953	0	0	5.3	0
	C	0.250	4.5	1.2	10.1	3.7
	R	0.141	7.3	4.1	4.3	0
	A	0.958	0	0	4.8	0
	U	0.329	3.3	0	11.4	5
Terphenyl	I	0.897	0.1	0	2.4	0
	C	0.153	6.9	3.7	2.1	0
	R	0.051	12.5	9.5	5.1	0
	A	0.063	11.4	8.4	1	0
	U	0.530	1.4	0	0.7	0
Tetrachloromxylene	I	0.028*	15.6	12.7	18.4	12.6
	C	0.131	7.7	4.5	16.6	10.7
	R	0.911	0	0	0.2	0
	A	0.244	4.7	1.4	6.9	0.2
	U	0.698	0.5	0	2	0
Tribromophenol	I	0.701	0.5	0	0.1	0
	C	0.037*	14.2	11.2	28.5	23.4
	R	0.542	1.3	0	12.6	6.4
	A	0.187	5.9	2.7	0.4	0
	U	0.072	10.7	7.6	19.7	13.9
Triphenyl Phosphate	I	0.804	0.2	0	0.2	0
	C	0.921	0	0	10.6	4.3
	R	0.008*	21.9	19.2	19.8	14.1
	A	0.568	1.1	0	3.6	0
	U	0.034*	14.5	11.6	8.5	2

Table 6 displays the groundwater contaminants that produced significant regression ($p<0.05$) with each land use area. Only DB, Fluorobiphenyl, Fluorophenol, Nitrobenzene, Phenol, Tetrachloro-m-xylene, Tribromophenol, and Triphenyl Phosphate displayed significant regression by land use area.

Second each contaminant does not display significant regression with each type of land use area. For instance, DB only produces significant regression by land use area

with commercial (C), residential (R), and Agricultural (A) land use types (table 6), while Fluorobiphenyl only produces significant regression with commercial land use areas. Third different contaminants display different forms of regression by land use area and type. Some produce negative regression, in which an increase in a particular type of land use area will result in a decrease in the contaminant concentration (DB and commercial land use for example). However, other contaminants display positive regression with land use types, whereby an increase in a particular land use area will correspond with an increase in contaminant concentration. Figures 21-28 display the regression plots for the 8 contaminants that displayed either significant linear or quadratic regression with percentage land use area. Each has a positive or negative linear or quadratic regression with one type of percentage land use area. Quadratic regression tends to dominate the relationship between groundwater contaminant concentrations and percentage land use area, explaining more of the variation than linear model regression.

When divided up between the five land use types, the percent of agricultural land use area is the best predictor variable (with largest adjusted R^2 values) for determining contaminant concentrations of DB (fig. 21), Fluorophenol (fig. 23), and Phenol (fig. 25). For each of these, the quadratic regression model predicts an initial rise in contaminant concentration followed by a sharp fall as the percentage agricultural land use increases. This is the most prevalent pattern amongst groundwater contaminants. Other regression relationships of particular note with a similar regression pattern include Fluorobiphenyl and percentage commercial land use (fig. 22), Fluorophenol and percentage undeveloped land use (fig. 23), and Nitrobenzene and percentage commercial land use (fig. 24).

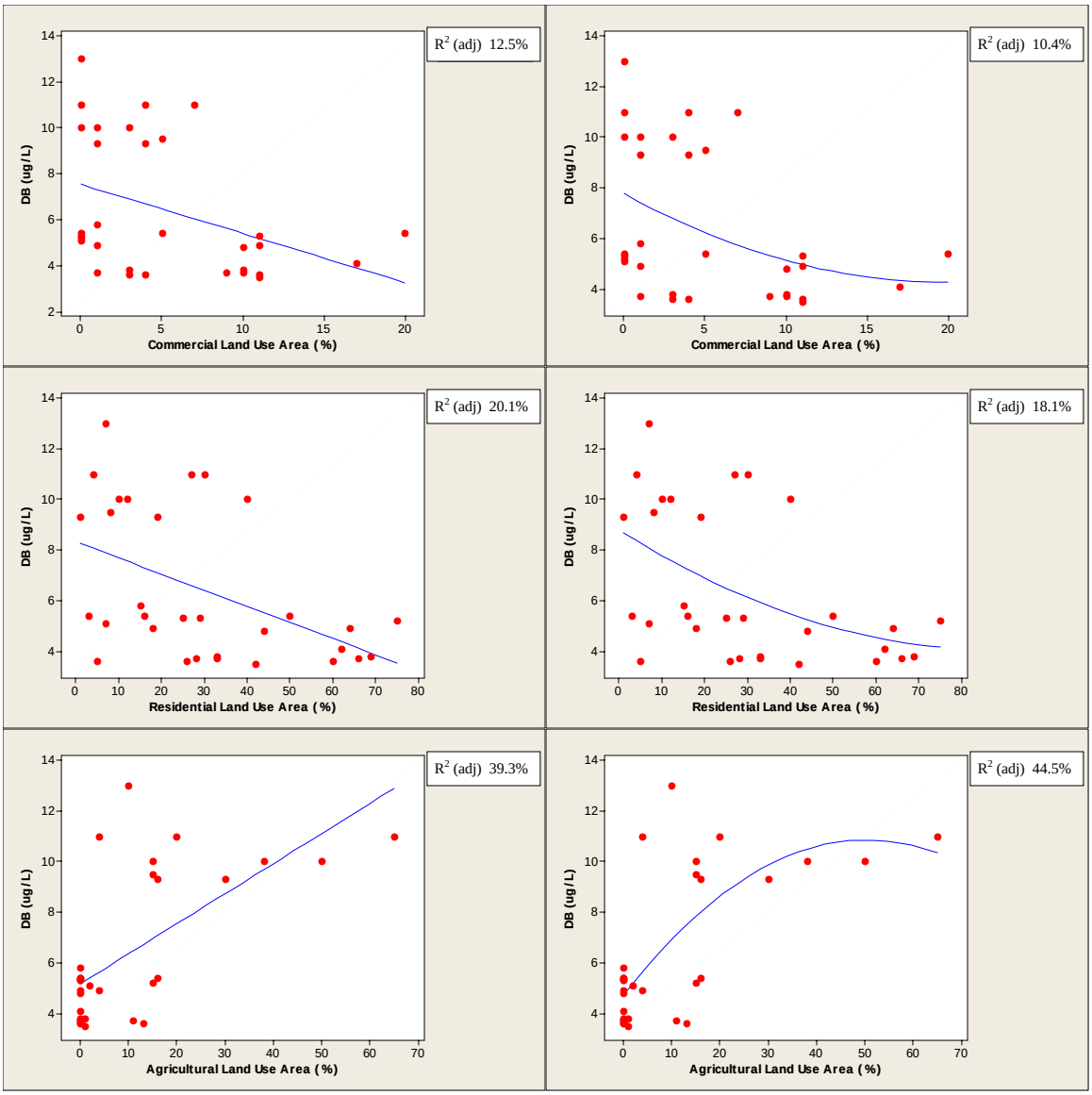

Fig. 21. Significant linear and quadratic regression analysis for DB.

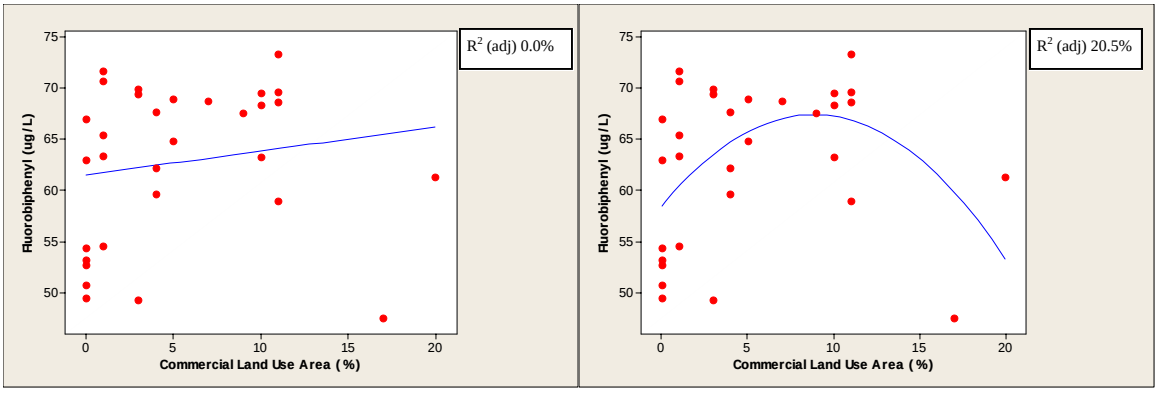

Fig. 22. Significant linear and quadratic regression analysis for Fluorobiphenyl.

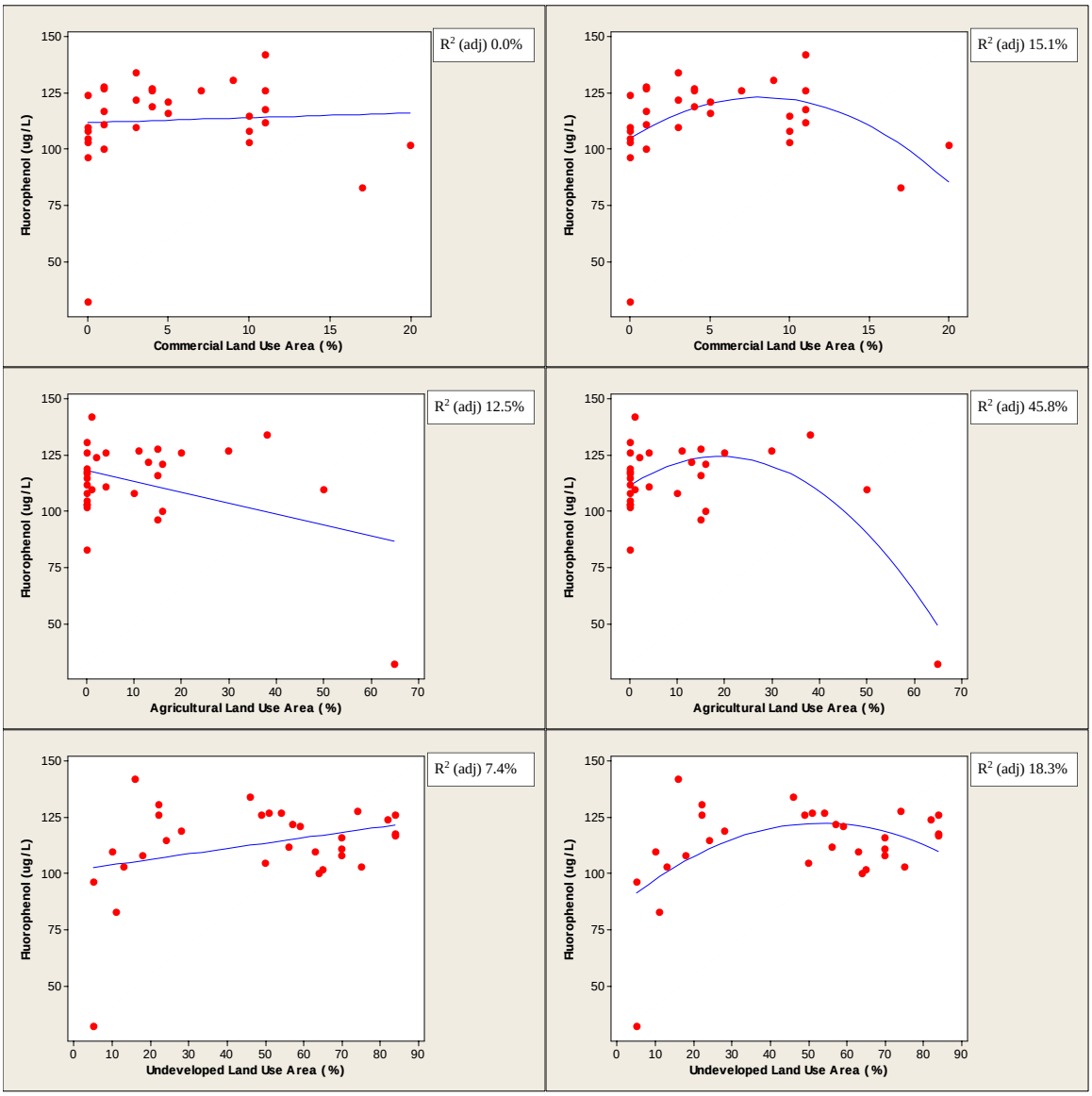

Fig. 23. Significant linear and quadratic regression analysis for Fluorophenol.

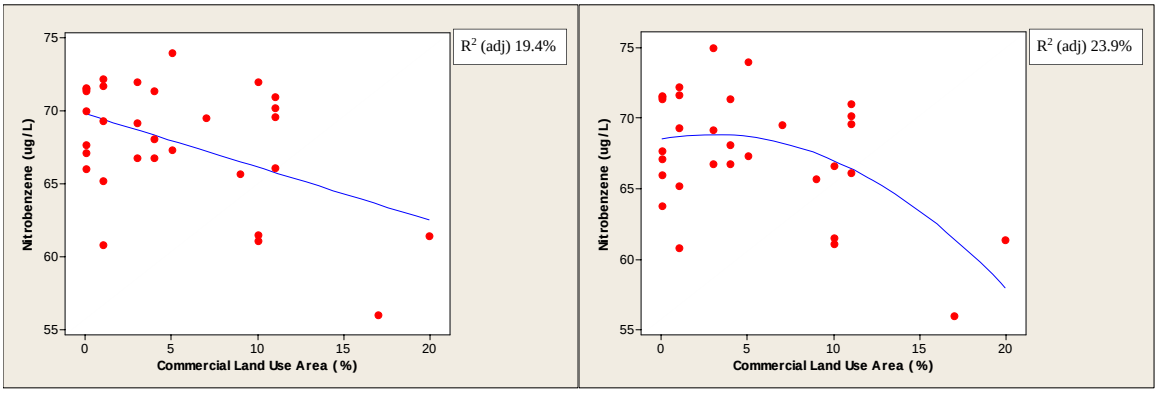

Fig. 24. Significant linear and quadratic regression analysis for Nitrobenzene.

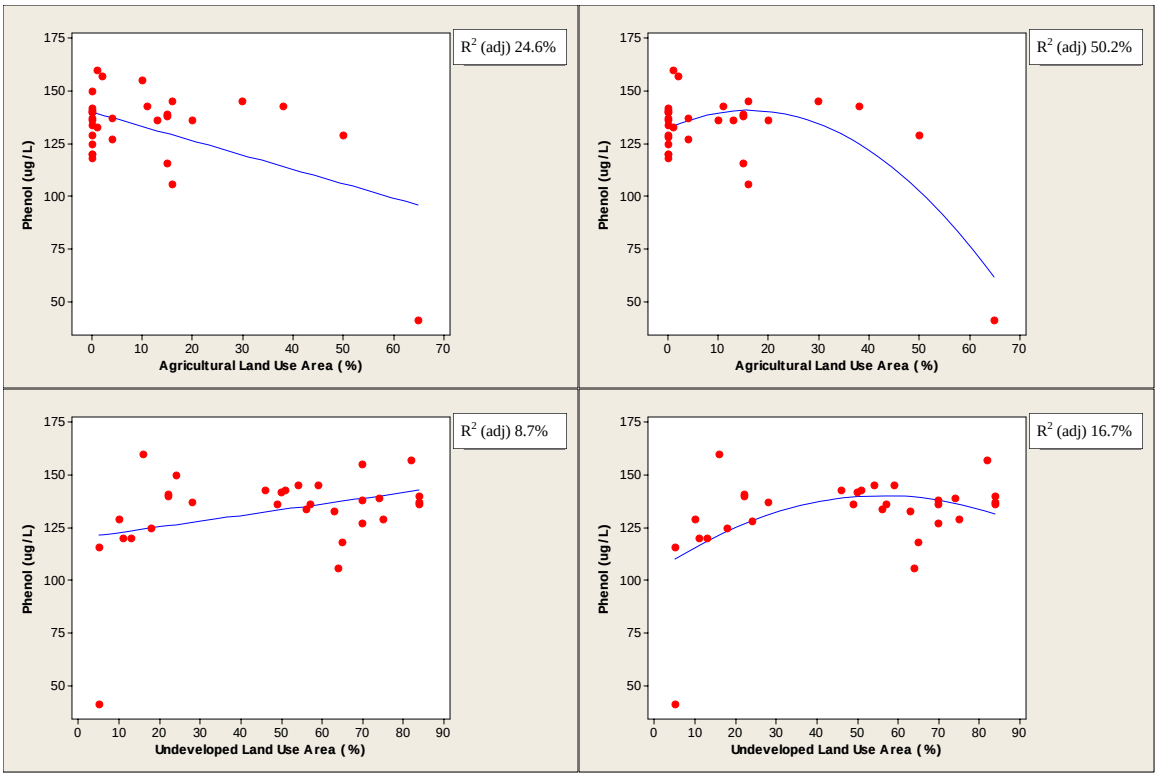

Fig. 25. Significant linear and quadratic regression analysis for Phenol.

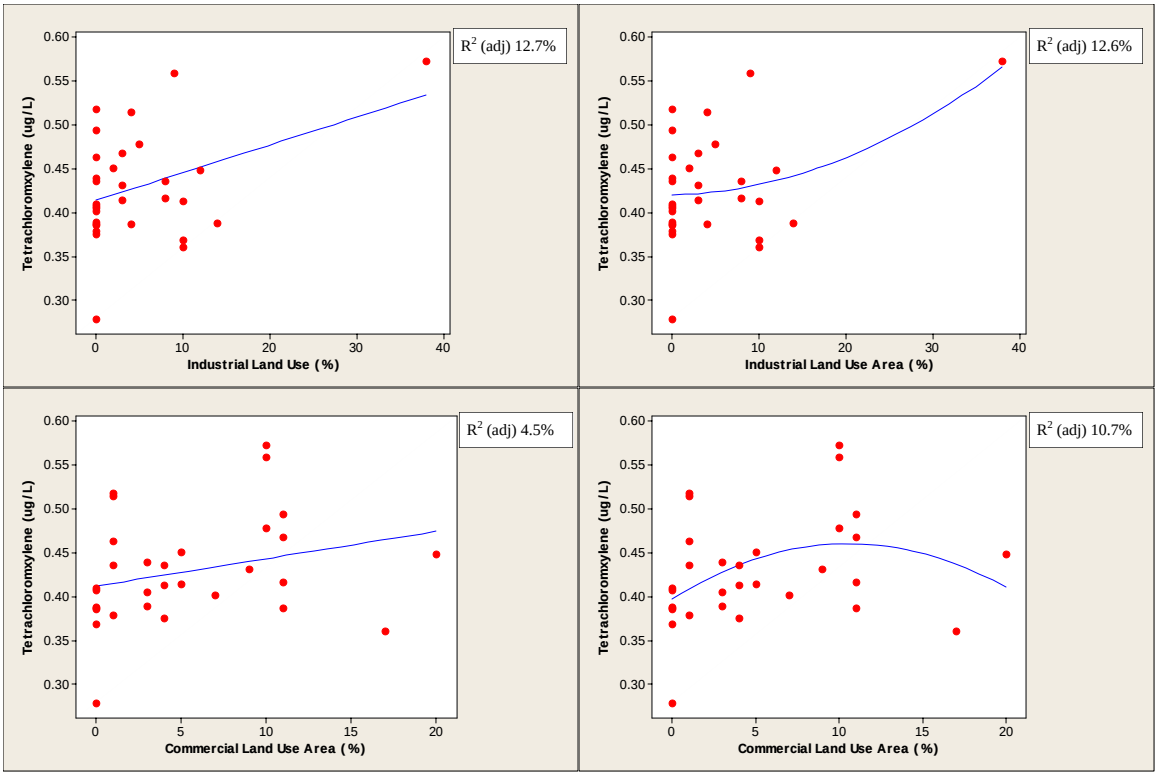

Fig. 26. Significant linear and quadratic regression analysis for Tetrachloro-m-xylene.

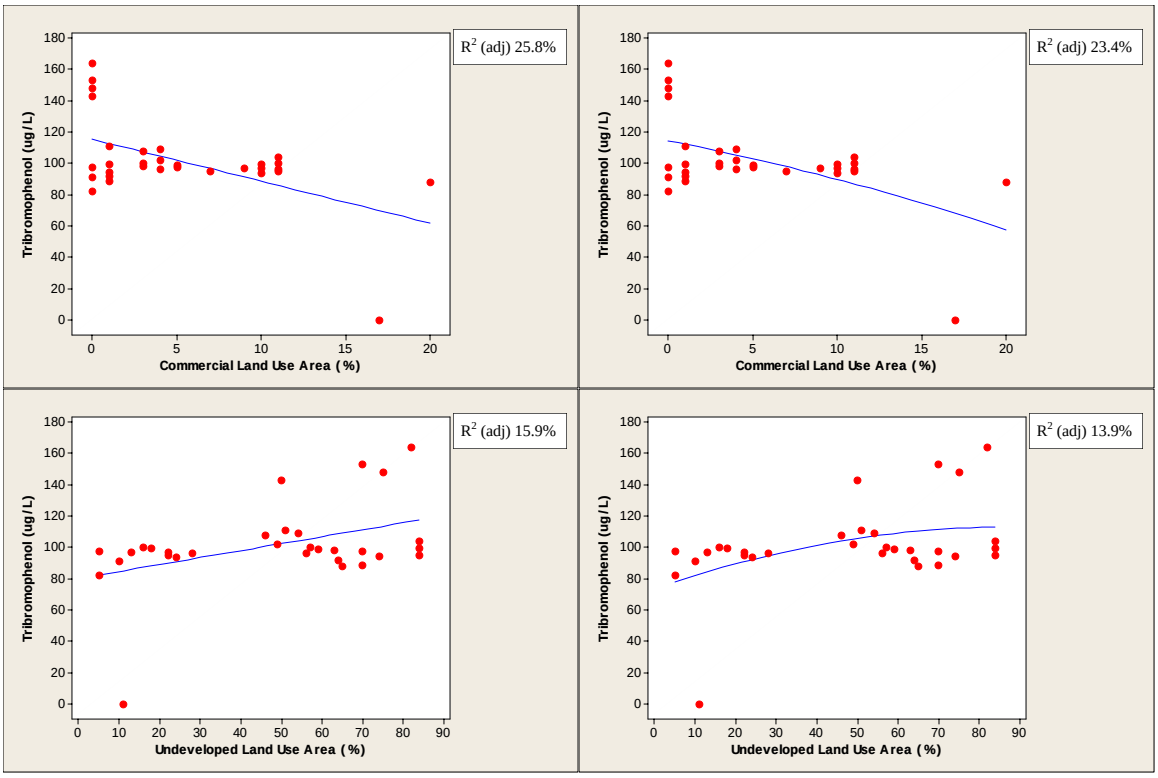

Fig. 27. Significant linear and quadratic regression analysis for Tribromophenol.

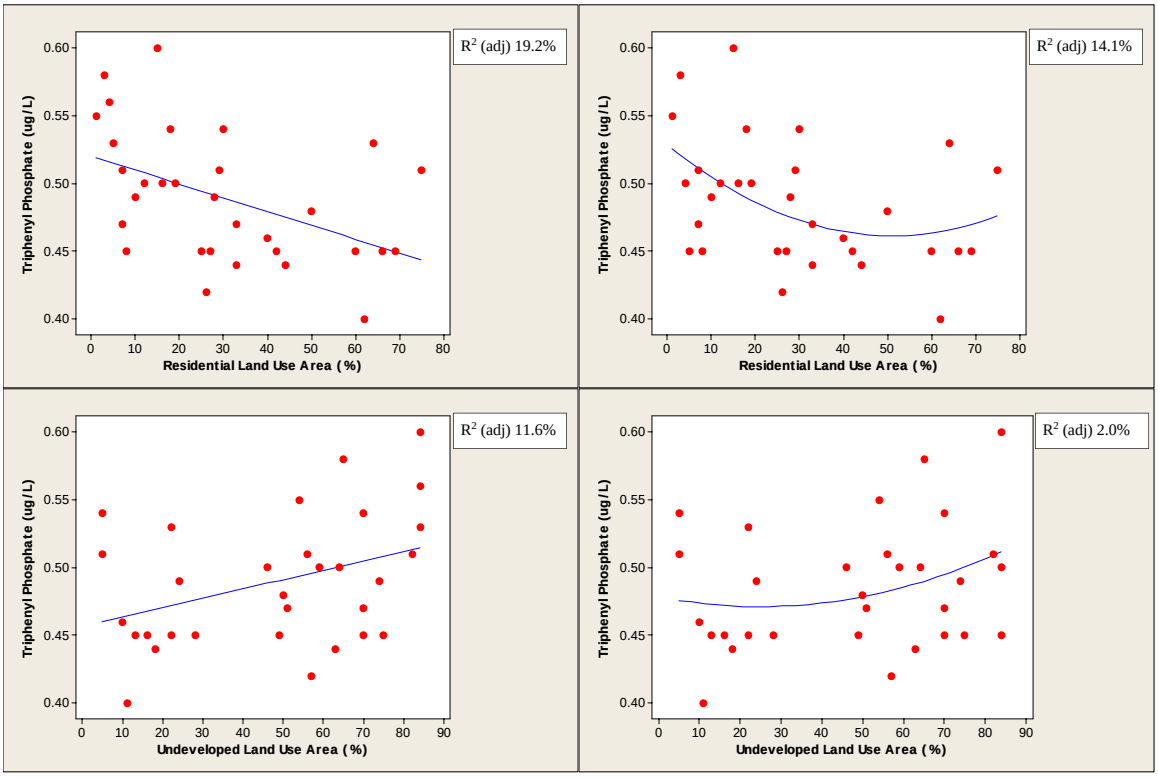

Fig. 28. Significant linear and quadratic regression analysis for Triphenyl Phosphate.

A regression relationship implies that the relationship between groundwater contaminants and percentage land use type is complex and hard to predict. Although significant ($p<0.05$), the regression relationships for the groundwater contaminants and percentage land use area by type are still weak as explanatory predictor variables, with the highest adjusted R^2 value being just 50.2% (fig. 25). Further evidence of this complex relationship can be found by viewing other relationships. Quadratic regression between DB and percentage commercial and residential land use (fig. 21), Tetrachloro-m-xylene and percentage industrial land use (fig. 26), and Triphenyl Phosphate and percentage residential land use (fig. 28) display a weak downwards convex relationship. As the percentage of each particular land use type area increases, the contaminant concentrations initially decrease before gradually increasing again.

Both of these types of regression relationships imply that there is a medial 'optimum' percentage of land use type area, where smaller and larger areas exert less influence on groundwater contaminant concentrations. Smaller areas should, in theory, produce less contaminants to enter the groundwater, while larger areas act to filter out a larger amount of the groundwater contaminants. The different degree to which this happens for each of the contaminants across the different land use types may be partially a function of how and where the contaminant enters the groundwater, and the path with which it moves through the aquifer.

Despite the 1.6 km buffering technique, groundwater contaminants are moving around the aquifer such that industrial contaminants are present in non-industrial areas. However this could also result from these contaminants entering the groundwater at non-industrial land use points. Many of these contaminants are now used in homes and offices

in everyday products (table 1). These could easily be introduced into the groundwater via sewers or small spillages at these locations, thus accounting for industrial contaminants at higher levels in non-industrial areas.

CHAPTER V

CONCLUSIONS

An analysis of groundwater contaminant concentrations within the BSEA concerning different types of land use produces some important findings. Firstly, regarding the Kruskall-Wallis analysis, the null hypothesis can be rejected for the following groundwater contaminants: DB, Nitrobenzene, Phenol, Terphenyl, Tribromophenol, and Triphenyl Phosphate. Each of these contaminants displayed significantly ($p<0.05$) different median concentrations between industrial, commercial, residential and agricultural land uses.

Secondly the median concentrations of these contaminants tended to be higher in land use types where these contaminants could reasonably be expected to be used or applied. This raises important questions about the uses of these contaminants across the BSEA, and if they are entering the groundwater at detectable levels. Continued monitoring is advised at these wells to check that contaminant levels do not begin to exceed levels regulated by the Safe Drinking Water Act (SDWA). The SDWA is consistently amended to include new contaminants nominated for inclusion. Although only four of the contaminants checked in this study are currently included within the SDWA and none exceeds maximum contaminant levels (DB, Dichlorobenzene, Nitrate, and Tetrachloro-m-xylene), this should not be regarded as insignificant. This scenario could change over time and across the aquifer itself as land use continues to change.

Thirdly, the other contaminants monitored here may be amended to the SDWA in the future. The EPA has already started its next phase of contaminant listings to be included in the Act which will regulate these new contaminants and establish maximum contaminant levels (EPA 2007). Nitrobenzene (included in this study) is among many other contaminants in this latest list.

Monitoring of wells for these contaminants, and other contaminants if possible, is further advised as it has been demonstrated that it is extremely difficult to account for contaminant concentrations just by percentage of particular land use types alone. Other factors including how these contaminants are entering the groundwater will be crucial in determining the concentration of these contaminants at particular locations within the aquifer.

This opens up the possibility of much further work that could be carried out regarding groundwater contaminants and their relation to land use for the BSEA that is beyond the scope of this study. A better understanding of the groundwater movement within the aquifer is of major importance relating to this study and will provide water planners with the means to track and monitor the dispersion of any contaminants entering the aquifer in order to better explain contaminant behavior within the aquifer and why some contaminants may be found in higher concentrations in some wells, but not others.

Another crucial aspect that is missing from this study is more frequent and wider monitoring of groundwater contaminants within the aquifer. Only 14 contaminants are investigated in this study, but many more may be present within the BSEA that deserve equal attention. Many contaminants can enter the aquifer from numerous day-to-day sources, including common commercial weed killers like RoundUp. The active

ingredients in this weed killer contain 1,4 Dioxane which is a known carcinogenic that can damage many of the vital organs of the human body (Chemical Land 21 2006). Common asphalt sealants used to pave roads and driveways also contains the known carcinogens Bentonite and Polycyclic aromatic hydrocarbons (Henry Co. 2006). These contaminants are widely used and can be washed into groundwater shortly after being applied to the ground surface. It is contaminants like these which must be closely monitored as there are no regulations currently governing their use, especially within the private sector, yet they can do the most damage to the quality of the BSEA.

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