SITE SPECIFIC DESIGN / LANDSCAPE ELEMENTS IN MITIGATING PARTICULATE MATTER: A CASE STUDY OF THE RESIDENTIAL AREAS OF TUCSON

by

Dipasusita Chundur

A Master's Report submitted to the faculty of the

DEPARTMENT OF PLANNING

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE
WITH A MAJOR IN PLANNING

In the Graduate college

THE UNIVERSITY OF ARIZONA

TUCSON

AUGUST 1998

ACKNOWLEDGEMENT

I would like to thank Dr. Barbara Becker for her guidance, patience and support throughout the entire time I worked on this report. I would like to thank Dr. Adrian Esparza for the help and input I received in finishing the report. I would also like to thank Mr. Martin Yoklic for helping me with the analysis, and a special thank you to Dr. Mary Kay O'Rourke, who gave me the opportunity to work on this project by providing me with the necessary data.

I wish to take this opportunity to thank Mr. Seumas P. Rogan, for helping me with the interpretation of the database and for all the G.I.S help I needed. I would like to thank Karen Young for always being there to help and support my entire graduate life.

Last, but not the least, my parents who have been my inspiration and support.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES: APPENDIX D

BACKGROUND

This master's report examines the usefulness of site specific design and / or landscape elements in mitigating the level of air particulates in individual residences. The research question was developed based on the particulate matter data (PM_{10} $\mu g/m^3$ and $PM_{2.5}$$\mu g/m^3$) collected from health related studies conducted in the residential areas of Tucson. The Respiratory Sciences Health and Environment Project Center at the University of Arizona conducted these studies. The studies indicated that long-term exposure to even moderate concentration levels of air pollutants have adverse effects on efficient respiratory functions in humans.

Air pollution and air quality have always been an important and integral part of a city. We think immediately of smog and haze caused by automobile fumes and industries when considering the urban air pollution. Hence air quality and control in an urban environment have always been at a regional scale and commonly are focussed on the source of these noxious elements. Federal standards are set to control the urban air quality. These standards have to a great extent helped mitigate air pollution. Many studies such as the ones conducted by the Respiratory Science Center have indicated that the problem does not stop when regulations are implemented.

Efforts should be made by planners to mitigate these pollutants through more effective urban design techniques. To access the feasibility of mitigation it is important to look at site-specific evaluation. These evaluations focus on the success of design and landscape elements, and wind patterns and other climatic variable within the sites, in mitigating micro-level pollutants at a home. In existing built environments it is practical to attempt mitigation on the individual lot as well as at the regional design/ landscape level. According to Rydell, and Schwarz (1968) Hough (1995), and White (1994), design/ landscape elements such as, land cover type, vegetation, yard material, orientation of property and overall subdivision-layout, with consideration for the wind pattern within the property and subdivision are believed to make a difference in the pollution level.

Thus, this report evaluates specific sites in an urban environment to determine if any design techniques and methodology can be used to mitigate particulate pollution at the individual lot level.

CHAPTER 1: AIR POLLUTION AND AIR POLLUTION CONTROL

INTRODUCTION

"The air over a city is both a life line and a sewer" (Rydell and Schwarz, 1968 pg. 119). According to Norman (1972) pollution originates as wastes from the production and consumption activities in the urban system. The author states that wastes created as gases, solids, liquids, and noise are termed 'pollutants' only when they cause damage to third parties and are classified according to the environmental medium through which they exist.

Air pollution affects the well being of the community and the environmental quality. According to Rydell and Schwarz (1968), there are three methods through which air quality is determined. The first is through citizens who often complain of smog and haze. Second is a more quantitative approach through the evaluation of the impact of air pollution on health. It is well known that pollution affects the physical health. The third method is from economic analysis. According to White (1994) environmental pollutants from urban development and lifestyle of the urban landscape can be categorized into two groups. One is gaseous residual that is discharged from vehicles, buildings and industries into the air. The other is solid and liquid wastes that are discharged into the water bodies and the ground. Of these two, the most concern is the immediate health implications of uncontrolled or poorly controlled discharges into the air.

The particulate matter suspended in the air has the most direct consequences on human health (White 1994). According to the World Health Organization (1992) the concentrations of air pollutants prevailing in many urban areas are sufficiently high to cause increased mortality, morbidity, deficits in pulmonary functions and cardiovascular and neurobehavioral effect. Some of the major pollutants under consideration are grit and dust, smoke, SO_2 and carbon monoxide. Of these pollutants, grit and dust (heavy solid particles mostly from roads and exposed land) give rise to most of the complaints from the public (Craxford, 1966).

PARTICULATE MATTER AND AIR QUALITY

Air pollution is referred to as the contamination of the earth's atmosphere by man-made compounds released into the air (Puget 1998). This is true in most cases because many human activities lead to the disturbance of the natural environment that creates contamination. Air contamination has raised many concerns among the community. This concern has throughout history led to research and studies in different fields and ultimately policies and control strategies (EPA 1998). However, regulations at the national level had to be moderated for practical reasons and have hence resulted in federal standards falling short of the objectives and acceptable limits. This has been found to have a considerable effect on the health of the people.

PARTICULATE MATTER

Particulate matter (PM) are small solids or liquids suspended in the atmosphere. Particles are categorized into two classes. First, those particles which are less than 10 micrograms and larger than 2.5 micrograms are 'coarse particles', and second, those particles smaller than 2.5 micrograms are 'fine particles' including 'black carbon' pollution (EPA 1998). Coarse particles are few in number but large in mass and constitute 30 - 50 % of the total mass of particulates. The mean size of the coarse particulate (PM_{10}) is 5 to 10 micrometers; and, for fine particulate ($PM_{2.5}$) the size is .3 micrometers. Fine particulates are important in terms of their effect on health and visibility.

AIR QUALITY

Air quality criteria has been set for major air pollutants such as carbon monoxides, SO_2, total suspended particles, hydrocarbons, and lead. The Environmental Protection Agency (EPA) is required to set national air quality for the six 'criteria' pollutants. Particulate matter is one of the six principals. These standards are normally categorized as primary (health based) and secondary (welfare-based).

The standards for the criteria pollutants were first established in 1971. These standards set an upper limit below which it was considered a safe level for health. The area that did not meet these standards was termed 'non attainment areas' by the Clean Air Act in 1977. Local and state governments were then required to take measures to curtail the level of pollution (Sauerwein 1980). The standards prior to 1987 regulated only total suspended particles (TSP) which included particles greater than 10 micrometers as well less than 10 micrometers. According to EPA research conducted during the 1980's indicated that the health problems were more from particles less than or equal to 10 micrograms. Hence, EPA revised the standards in 1987 focusing on PM_{10} and $PM_{2.5}$. The new 1997 EPA standards for $PM_{2.5}$ are set at 15micrograms (annual) and 65 micrograms (24 hour). The PM_{10} is retained at the previous rates of 150 $\mu g/m^3$ (24 hours) and 50 $\mu g/m^3$ (annual) (EPA 1998).

SOURCES OF PARTICULATE MATTER

Natural sources of primary particles (size is up to 100 micrometers) are dust raised most often by wind. Secondary particles (very small particles) are produced naturally from vegetation. In most areas where development has taken place, the sources of primary particles are mostly from automobile emission. Secondary particles are created from vapors of hydrocarbons, NO_2, and SO_2. The coarse particles contain iron, silicon, aluminum, calcium, sodium, and chloride; while fine particles contain carbon, lead, ammonium sulfates, and ammonium nitrates. The particulate size between 1 μm to 10 μm are from re-suspended dust from the ground, natural organic debris, tire/road fragments. PM_{10} in arid regions is primarily from wind blown dust. Also local concentrations of PM are from heavy industries and heavy auto and truck traffic (Geddes 1997).

EFFECTS OF PARTICULATE MATTER

HEALTH EFFECTS

According to the Environmental Protection Agency, the greatest effect of pollution is on children, the elderly, and people with lung problems such as asthma, allergies, and emphysema. EPA concluded that the coarse particles that are inhaled accumulate in the respiratory system and aggravate asthma. The finer particles on the other hand penetrate deeper into the lungs because of their size. These fine particles cause severe health problems, some resulting in premature mortality. In desert areas there is an additional health problem of valley fever spores, which are carried by the wind, especially when the desert landscape is disturbed by vehicles or construction equipment. These adverse health problems have been observed even in areas where the level of particles were well below the PM standards, which were set in 1987 - 1997, for both short term (between 1 - 5 days) and long term (one year to several years) periods (EPA 1998)

WELFARE ISSUES

The most noticeable change brought about by the particles in the atmosphere is the reduction in visibility. This is very evident in Arizona where the clear day visibility range is 140 miles and can be reduced in most areas to 33-90 miles. In the eastern part of the country the natural visibility was reduced from 90 miles to 14-24 miles (EPA 1998). The high concentrations of particles, due to their inherent property to scatter and absorb light, reduce the amount of sunlight reaching the ground. This effect produces haze thereby reducing the visibility range. The increase in pollution levels has led to the use of more artificial light. This phenomenon is significantly evident in the winters when the pollution loading is higher and sunlight has to pass through denser air (Fogiel 1988). The particles can also cause damage to building materials by abrasion, deposition and removal, direct and indirect chemical attack, and electrochemical corrosion caused by airborne particles when they hit against the surface of the building. Such destruction to the built environment has significant economic ramifications over time. This type of damage serves to demonstrate the potential health and welfare issues associated with particulate pollution.

ELEMENTS TO BE ADDRESSED IN CONTROLLING AIR POLLUTANTS

The impact of air pollution on an urban system depends on the sources of the gases. Industries, urban infrastructure, and transportation, apart from other gases, produces particulate material that build-up tropospheric ozone which leads to a decline in urban air quality (White 1994). Thus the urban form plays an important role in the impact caused by air pollutants. It is believed that an element to element approach of the urban forms such as building, streets, industries, transport modes and open spaces can be individually designed to reduce air pollution (Rydell, and Schwarz 1968, Hough 1995).

The dispersion and transportation of pollutants are caused by the urban microclimate, specifically the wind speed and vertical temperature gradient. The design layout of the city or neighborhood can cause a significant reduction in wind speed relative to adjoining areas, allowing air pollutants to accumulate (Rydell. and Schwarz 1968). The balance between the rate of emission and the rate at which the pollutants are blown away by the wind determines the concentration levels to which people are exposed. Therefore, dispersion of pollutants and the way the urban microclimate is structured is important (Craxford, 1966).

According to Wood (1990) the use of land-use and design techniques, such as design of the house and overall site with respect to climate and buffer zones at neighborhood levels, helps in controlling the levels of air pollution. It can be assumed from such studies that individuals can create healthier microenvironments (homes). Each of the design elements around homes and in neighborhood can have important implications on the health or the local environment.

WIND PATTERNS

The impact of air pollution can be altered by the way every building and street is designed and constructed. Since these elements alter the topography on the area, they affect the local temperature and wind patterns (the two principal determinants of atmospheric diffusion) and, in turn, assist air pollutants to concentrate in areas. The orientation of a single building with respect to topography or local winds can influence dispersion, since eddies may be generated which cause pollution from one building to affect another (Norman 1972). If a home is situated so that prevailing winds are constantly bombarding windows and doors, airborne pollutants such as particulates will invade the home at high levels. A constant exposure to wind borne pollutants may cause allergies or other health concerns. In desert regions the prevailing winds over exposed soils can cause particulate pollution to rise.

GROUND COVER AND BUILDING MATERIALS

Building materials and soil content influence the microclimate and affects particulate pollution levels (PM). According to Rydell and Schwarz (1968) masonry heats and cools slowly, remaining warmer in the early evenings and warming up later in the mornings. This means that the type of masonry used to build homes should be compatible to the region it is to be utilized in. Gravel around a structure creates a local desert-like climate that encourages air to heat and rise, creating cooling circulation. Hence the use of gravel acts as a barrier and keeps small particles from being lifted.

PLANNED OPEN SPACES

Open spaces, especially if planted with grass, shrubs, and trees help in reduction of air pollutants by absorbing them (Norman 1972). Greenery absorbs moisture and cools by evaporation, causing a cooler more humid climate than stone and exposed soil. The temperatures on grassy area on summer days especially are 10 to 15 degrees cooler than over exposed soil. This cooler, moist air prevents dust formation. The concentration of pollution decreased by about half over 500 meters of open space and by two-third of five-sixth over 500 meters of planted land in one study (Rydell and Schwarz 1968).

BUFFER ZONES AT NEIGHBORHOOD OR REGIONAL LEVELS

Buffer zones are often used in improving the appearance and value of the property. However, in most cases buffers are not useful in diluting pollutants because they are usually narrow strips varying between 8 to 150 feet in width. These buffers are more effective in reducing the levels of pollutants when they are strategically placed in relation to wind patterns (Rydell and Schwarz 1968). These strips can be placed in the path of the prevailing wind, between residential areas and roads/highways or industries at a regional scale.

AIR QUALITY IN ARIZONA

The impact of particulate pollution (particulate matter) on the urban environment is from prevailing climatic conditions, the topography of the region, the use of automobiles and the location of light and heavy industries. Arizona's unique desert climate and landscape has contributed immensely to its rapid urban development. This rapid growth affects the state's overall air quality. Controlling the air quality has been difficult for Arizona, because of the combination of a desert environment and rapid growth compounded by the lack of efficient control techniques and lack of planning for environmental mitigation (Bennett 1988).

Residential preferences also play a major role in Arizona's air quality. Single family dwellings are very typical of an Arizona lifestyle (76.3% in Tucson). This has led to urban sprawl and the proliferation of single occupant vehicles and continuous disturbance of the landscape. With urban pollution directly related to the number of miles traveled by vehicles, sprawl has created significant pollution in the urbanized areas.

It is not surprising that there are different sources of pollution for urban and rural areas. In rural areas the problem is practically one of particulate matter from road dust, wood burning stoves and fireplaces, off road vehicles, agricultural activities and trash burning. In urban areas, the combined effects of desert climate and automobile emissions are the greatest contributors to poor air quality. Since pollutants always drift from one place to another regardless of their sources, residents at the urban fringe are likely to experience significant rural as well as urban pollution (Bennett 1988).

EPA's standards present some problems. Federal strategies and solutions to lowering air pollution are based on analysis done at the national level. Hence, they might not reflect the actual conditions of Arizona. Because of Arizona's unique climate, the State may not meet EPA's minimum standards for particulate matter in the air, although they will be applied to Arizona. The State has to develop and justify its own stricter standards and strategies for controlling visible pollution (Bennett 1988). It would be more healthful for Arizona residents if pollution control techniques could be adopted and practiced more at the micro level to reduce pollution exposure.

PIMA COUNTY /TUCSON

In Tucson the primary source of PM_{10} is from unpaved roads, unpaved road shoulders, exhaust emissions, earth moving, construction, agricultural activities, and the natural desert environment. Fortunately, for Tucson there has been no violation of federal standards since 1987 (Department of Environmental Quality 1995). According to the Tucson Advisory Commission, the major sources of PM in Tucson are from sand and gravel operations and dust from the above mentioned sources. Other minor sources are from fireplaces in homes and incinerators from schools and hospitals. These minor sources form an important part of the local air quality (Caldwell 1971).

SUMMARY

Particulate pollution causes a lot of health and environmental problems. In Arizona and, specifically Tucson, the disturbed desert landscape is a primary source of particulates. Though the PM standards are below the federal regulations, there are persistent health problems due to long term exposure to the existing PM levels. It has been suggested, by Rydell and Schwarz (1968) and Norman (1972), that urban design and residential techniques can mitigate the particulate pollution and these include the use of gravel and or ground vegetation. Also, the use of buffer strips at regional and local levels in the path of the wind blocks the air borne particulates from being transported from one place to another. This study will evaluate the potentials of these techniques at individual homes, as particulate matter level is known for every individual site.

CHAPTER 2: A CASE STUDY OF TUCSON

INTRODUCTION

Tucson was chosen as a study area because data was available on particulate matter concentration in individual homes. This data was collected by the Health and Environmental Studies of the Respiratory Science Center at the University of Arizona from 1987-1993 as part of a health related research project. The results of the study indicated that the concentrations of air pollutants had adverse effects on efficient respiratory functions in humans. The study also indicated that large populations were susceptible to these pollutants. It was found that long term exposure to moderate levels of particulate matter affects the respiratory tract. The degree of susceptibility depends on the amount of pollutants people were exposed to and their individual health conditions (Quakenboss 1994).

The PM data collected was distributed over the entire Tucson basin and the PM levels varied at every site. Since the research question examines the usefulness of site specific design and landscape elements in mitigating particulate pollution, the PM data forms an important and integral part of this report. The first part of this chapter is a general description of Tucson. The second part discusses the research methodology adopted in the analysis.

TUCSON BACKGROUND INFORMATION

Tucson is located in the arid regions of southern Arizona at an elevation of 2500 feet. Mountains surround Tucson on the north, east, and west sides ranging from 5000 to

9000 feet. This natural valley in which Tucson is located increases the potential for air pollution since air is trapped easily in the basin. The Santa Cruz River once flowed through the city and its dry riverbed further emphasizes the arid setting for the city. The Rillito Creek Wash and the Canada Del Oro Wash are the main tributaries for the Santa Cruz River. They, too, remain dry during majority of the year

HISTORY AND GROWTH OF TUCSON

The Santa Cruz River was the hub of the first settlement, in the eighteenth century. Tucson at that time was a two square mile town. The initial growth of Tucson can be divided into two phases. The first influence was the Southern Pacific Railroad in 1880 when the first track was laid. With the railroad, Tucson grew rapidly through annexation in the early 1900's. The second phase of growth took place after 1940 due to the Davis - Monthan Air Force Base that was built during World War Two. This second phase of growth started the urban sprawl, which continues today.

VEGETATION AND CLIMATE

Tucson is located in an arid region with hot and dry climate for most of the year. According to Duffield and Jones (1990), who categorized all arid regions into three zones, the Tucson area encompasses two arid zones. The majority of the city sits in the medium zone of 2500 ft. It experiences mild winters and is subjected to summer showers. Though the region experiences adequate rain, moisture does not stay in the soil due to the high evaporation rate. Though the summers are very hot and dry, some cool weather plants can thrive in the desert because of the drop in temperature at night.

In the Catalina foothills, between 3300 to 5000 feet in the southern latitudes, temperate vegetation is very typical. The vegetation in Tucson is typically of the lower Sonoran Life Zone (Lowe, 1972). The Tucson valley is characterized by shrubs and is dominated mostly by creosotbush (Steenburgh and Warren 1977). The foothills and areas with coarse soil have paloverde-saguaro as the dominant vegetation cover. This sparse vegetation found in both the valley and foothill areas allow for greater particulate matter to be air borne than in areas where ground cover vegetation is abundant.

Weather and climate are also important factors in the air pollution problem. Meteorological factors that impact air quality are: vertical stability, wind speed and direction, solar radiation, day length, precipitation, weather sequence and persistence.

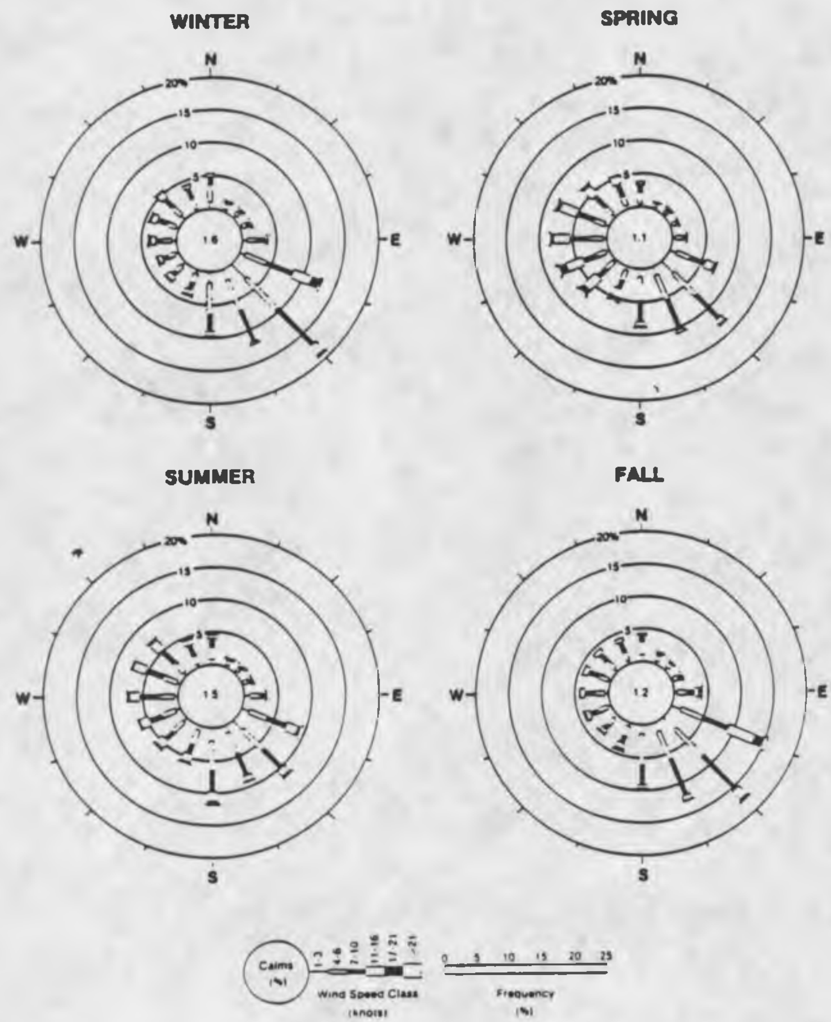
Pollution is also dependent on the geographical location. Cities like Tucson that are surrounded by mountains have a tendency to trap pollution within their air shed (Bennett 1988). Wind speed in Arizona is the lowest in the country with an average always around 10 miles per hour. The exception is during storms. However, these are infrequent since Arizona's climate is controlled by the subtropical high-pressure region, a mass of air characterized by clear, calm weather for much of the year. Figure 1 shows the average wind direction for the Tucson region. The wind patterns are from the northwest to the southeast and vice versa during the spring and summer and from southeast to the northwest during fall and winter. However, the wind pattern shows a strong flow generally from a southeast to the northwest regardless of the season. Thus, any air pollution created in the Tucson area generally moves away form the core. This makes the

Tucson area an exceptionally good place to study the possible effects of landscaping on air quality at a microlevel.

Figure 1: Seasonal Wind Speed and Direction for Tucson, Arizona

TUCSON AVERAGE WIND ROSES FOR SEASONS OF THE YEAR

Note the strong southeasterly to west-northwesterly components to wind direction, basically in line with orientation of the Santa Cruz River Valley. Very few cases exceed 21 knots (approximately 24 miles per hour).



Source: Bennett, A. ed: 1988. *Air Quality in Arizona.*

RESEARCH METHODOLOGY

The first part of this section describes the source and method adopted in collecting the particulate matter database that I used in the analysis. The second part of the section describes the methodology I used in examining the usefulness of design and landscape elements in mitigating particulate pollution.

PM SAMPLE COLLECTION METHODOLOGY

The particulate matter (PM) data for this report was obtained from the database of two studies conducted by the Health and Environmental Study of the Respiratory Science Center. The first study was called the 'PH' study conducted from 1988 to 1992 that focused mainly on the Tucson area. The second study was called the NHEXAS study (National Human Exposure Assessment Survey) and was a statewide project beginning in 1995. The Tucson area was sampled during 1996. A random sampling technique based on census tracts and block group was used in selecting the houses for the projects.

The PM sampler (box) was placed in every house to measure the particulate matter concentrations. The particulate matter was collected for $PM_{.2.5}$ and PM_{10} inside every selected home. Only 10% of these houses had outdoor PM values (in the yard) taken. The outdoor PM data was collected in these houses through carefully monitored surveying techniques for a sampling period of one week. There were a total of 70 houses with outdoor PM values spread over six years. Map 1 (Appendix A) shows the various outdoor sampling locations for $PM_{10}\mu g/m^3$.

PM SAMPLER

There are two main components to the sampler, the pumping and control unit (black box) and the metal impactors. The pumping unit is designed to pull in a sample of air at a constant flow rate (4 SLPM, Standard Liters Per Minute) during pre-set time period, and to switch this flow from one sample line to another at pre-set intervals. This switching is done with a timer-controlled solenoid valve that directs the flow from the pump through one of the two sampling lines. This sampler has a built in mass flow sensor that adjusts the speed or cycles of the pump as temperature or pressure vary. The PM_{10} impactors are placed on the ends of the sample lines, and are designed to remove particulate matter (PM) larger than 10 microns before the air is drawn through a filter that traps the remaining PM of 10 microns in diameter or less. The $PM_{2.5}$ impactors remove PM larger than 2.5 microns before the air is drawn through a filter that traps the remaining PM of 2.5 microns in diameter or less (Lebowitz 1993).

CALCULATION OF $PM_{10}\mu g/m^3$ and $PM_{2.5}\mu g/m^3$

The filters used to collect dust for particulate analysis are weighed before and after sampling is completed to determine the mass of PM collected during the time period that the pumping unit was active. These weights are calculated under very controlled conditions. The following formula is used (Lebowitz 1993):

[Sample weight in µg / (flow rate in liters/minute) (elapsed time in minutes)]*1000 liters/cubic meter = $\mu g/m^3$ of air sampled.

OUTDOOR SITE CRITERIA

An important site criteria is, the location of the pumping unit which was placed on the north side of the house, ten feet from the midpoint of the wall. Placement on the north side of the house was intended to protect the sampler from direct sunlight. The sampler should not be located under trees, near pools of standing water, near animal cage or under tables, porches, nor, near obvious sources of contamination such as roads, alleys, sand-pits, etc (Lebowitz 1993).

STANDARD QUESTIONNAIRES

Questionnaires were used to record the location of the PM sampler, fireplace, barbecue grill and any other nearby sources of particulates. These questions help in keeping a record of the important elements and activities at the time the sample was taken.

METHOD USED IN SELECTING THE TWO STUDY AREAS

The sites were located more on the pherphery of the city as seen in Map 1(Appendix A). The 70 houses were sampled only once and hence it was difficult to study the trend of the PM levels at each site. The map shows a cluster of sites on the northwest side. There are 16 sites which were distributed over the six sampling years. This was taken as one study area. Map 2 and map 3 show the northwest study area for PM_{10} and $PM_{2.5}$ respectively (Appendix A). There was another cluster on the southeast side. To maintain the same number of sites on either side, the second study area was taken from the Tanque Verde Wash on the north to Davis Monthan Airforce base on the south. This area is referred to as the southeast study area and has 15 sampled sites. Map 4 and map 5 shows the southeast study area for PM_{10} and $PM_{2.5}$ respectively (Appendix A). The two study areas were selected to do a comparative analysis of sites. The southeast study area is a higher density urbanized area compared to the northwest. Another reason to compare this area to the northwest area is the proximity of the highway to the northwest area.

METHOD USED IN THE SITE SPECIFIC ANALYSIS OF THE TWO REGIONS

A detailed site survey was conducted from mid February 1998 to the end of April 1998. Attempts were made to contact all 31 houses (16 houses on the northwest area and 15 on the southeast area). Out of the total 31 homes, 7 respondents had moved, 12 respondents no longer wanted to participate leaving a total of 12 eligible homes. Hence site specific analysis was conducted in only 6 homes in each study area.

Site-specific design and landscape elements that might contribute or mitigate the PM levels were identified (see indicators). Table 1 and Table 2 (Appendix D) summarizes the sites surveyed in Region 1 and Region 2 respectively. Site numbers refer to the houses surveyed. Sites1-6 represents Region 1 – The northwest study area, and sites 7-12 represent Region 2 – The southeast study area. The survey was conducted using various site-specific design and landscape indicators that were chosen based on the review of the literature discussion.

INDICATORS

The following indicators were selected based on their importance in previous research:

- **Yard cover**: Six types of yard cover variables were chosen. They include exposed soil, gravel, concrete, brick, lawn (irrigated), and wild grass / weeds. The variables were scaled on a scale of 0 – 5 from no coverage to 100% coverage. A new variable 'aggregate' is introduced to help in the analysis. The aggregate represents a combination of gravel, concrete, brick, lawn/irrigated.
- **Vegetation type**: Vegetation is divided into 3 variables: trees, shrubs, and other plants. The variables are scaled on a 0 – 4 scale based on the number of trees, shrubs, and plants present.
- **Paving**: This element represents the type of transportation network present: alley, driveway, road, thoroughfare, walkway/wash. The variables are scaled on a 0 – 7 scale depending on the paving type, 7 is for unpaved dirt which is considered as the highest source for particulates.
- **Fence type**: This variable is used to identify the type and properties of the fence around the site. It also indicates the openness of the yard.
- **Building materials**: These variables are used to indicate the material type used: brick, concrete block, wood.
- **Openness scale**: This indicator is used as a rough estimate to measure the openness of the yard to the wind. Two wind directions, northwest and southeast are used as variables. A 0- 5 scale, ranging from no flow to high exposure, is used to indicate the wind flow.

- **Precipitation scale**: The number of days it rained is expressed as a percentage. The percentage is obtained by dividing the number of days it rained by the sampling period. The total rainfall is indicated in inches.
- **Other variables**: Incidental, localized items are also considered such as number of dogs, presence or absence of a barbecue grill, fireplace, and swimming pool.

SUMMARY

The availability to site specific values for particulate matter concentrations makes Tucson the ideal place for studying the usefulness of site specific design/landscape elements in mitigating the particulate levels. The two study areas were chosen based on the distribution of the PM values. Design and landscape indicators identified from the literature were developed as tools of measurements to be used at each site. These measurements are used along with the PM levels in the analysis.

CHAPTER 3: ANALYSIS AND FINDINGS

INTRODUCTION

Design and landscape surrounding each dwelling unit affects the air pollution (PM) levels at each site (microenvironment). To determine if this is a valid assumption, this report analyzes:

1. The design and landscape features at each site and;

2. The relationship between the design/landscape features and the PM levels.

Graphs, individual lot layouts, and maps are some of the analytical tool used in this study.

To understand the site specific design elements that play a role in mitigating or acting as a source of particulate matter, it is first important to understand the overall regional factors that influence the PM levels. The first section of this chapter discusses the regional factors influencing the level of particulate matter. The second section is a case by case discussion and interpretation of the variables using graphs and lot layout.

REGIONAL ANALYSIS OF THE STUDY AREAS

The northwest study area is referred to as 'Region 1', and the south east study area is referred to as 'Region 2'. Some of the regional sources of particulate matter are the riverbed, major highways, roads, automobile exhaust, and vegetation. Map2 (Appendix A) shows that Region 1 is bounded by the Rillito river and I-10. The levels of PM_{10} here are higher because of the riverbed and major highway.

The wind patterns for most of the year blow from the north by northwest. The wind hits the St. Catalina mountain ranges as it turns into the Tucson basin depositing dust and other particulates. Some of this composition found in this area might be from the Santa Cruz riverbed, the I-10 highway and from the mountain. As it approaches the southeast part of the area it blows through the City, depositing and picking up dust and particles. Table 1 and Table2 (Appendix D) indicate that the PM levels in Region 1 are relatively higher than Region 2. This is most likely due to the previously discussed wind pattern in the region.

SITE SPECIFIC ANALYSIS: DESCRIPTION OF INDIVIDUAL SITES

REGION 1 – NW STUDY AREA

Detailed site evaluation was conducted in six sites. The PM concentration in these sites range from 14.18 $\mu g/m^3$ to a high of 38.03 $\mu g/m^3$ for PM_{10} and 7.56 $\mu g/m^3$ to a high of 19.39 $\mu g/m^3$ for $PM_{2.5}$. Analysis revealed that exposed soil and dirt are the main sources of PM_{10}. The following section describes each site in detail with the help of site layouts and photographs found in Appendix B and Appendix C.

SITE 1

Layout 1 illustrates the site (Appendix B.1.a). The backyard is located on the east side of the house. The yard is enclosed within a six feet high wooden fence. The yard is very open and contains desert vegetation. About 60 – 70% of the yard is covered by gravel. The swimming pool is located in the center of the yard. Another small pool is located between the house and the swimming pool. An alley abuts the eastern side of the yard, and the driveway is on the western side of the yard. The driveway is covered with gravel as seen in photograph 4 (Appendix B.1.b). Due to the openness of the yard, the wind flow is high within the yard. The fence acts as a barrier reducing the speed to the wind entering the yard near the ground level. Photograph 1 (Appendix B.1.b) shows the northwest corner that abuts the driveway on the other side. Photographs 1 and 3 (Appendix B.1.b) show that the fence and vegetation act as a barrier to the wind. Since most of the exposed soil in the yard is covered by gravel, concrete, brick, swimming pool, and desert vegetation not much dust is lifted from the ground. The swimming pool also acts as a filtering device and collects many of the particles that might have been blown in the wind. Photographs 2 and 3 (Appendix B.1.b) show the position of the pool and the landscape of the yard. Also pertinent to the study is the weather during the PM sampling period. There was rain at the time the sample was taken with .31 inches in total and it had rained for 43% of the sampling period (Appendix D, Table 1). This probably helped in lowering the PM_{10} value, as the soil would be damp and particulates would not be in the atmosphere.

SITE 2

Layout 2 (Appendix B.2.a) illustrates the site layout, which shows that the backyard is located on the south side of the house. A six feet high wooden fence encloses the yard. The yard is very open with 40 % – 45% of the yard covered with lawn. An alley abuts the south side of the yard. The alley is a dirt passage covered with weeds. Since 70%- 75% of the yard is covered with lawn, gravel, concrete, and wild weeds, not much dust/dirt is raised from the ground. Photograph 6 (Appendix B.2.b) shows the southwest corner of the site. The yard cover and openness of the yard is clearly seen in this photograph. The fence acts as a barrier cutting the winds at ground level. Photograph 5 (Appendix B.2.b) shows the east side of the yard where the PM sampler was kept. This photograph also shows that the area is enclosed and air movement restricted. This would result in lower PM_{10} level. Also pertinent to the study is the weather during the PM sampling period. There was rain at the time the sample was taken with a total rainfall of .29 inches and it had rained for 33% of the sampling period (Appendix D, Table 1). Both the weather condition and enclosed monitoring could have affected the accuracy of this reading.

SITE 3

The backyard surrounds the house on the north, south and east (Appendix B.3.a). A six foot high concrete block fence encloses the yard. The yard is fairly closed and is shaded by a huge mango tree on the east side (Appendix B.3.b, Photograph 8). The north and northeast part of the yard is very open as seen in photograph 10 (Appendix B.3.b). About 70% of the yard has exposed soil compared to the 30% coverage by the lawn, gravel, wild weeds. An alley abuts the east side of the yard, which is covered with vegetation as seen in photograph 9 (Appendix B: 3). The PM_{10} level in this house is a little higher than the first two sites. This increase in PM could be due to the exposed soil. Another factor that could have contributed to a higher PM_{10} concentration is the presence of a dog. Photograph 7 (Appendix B.3.b) shows the location of the sampler at the southeast corner of the site that was exposed to the pet and the open ground.

SITE 4

In layout 4 the yard surrounds the house on the north and west side (Appendix B.4.a). The site is located on a hilly area, as illustrated in photograph 11 (Appendix B.4.b) taken from the driveway. The yard is enclosed by a stone fence and has a lot of desert vegetation. Photograph 12 (Appendix B.4.b) shows the west side of the yard. The PM sampler was placed on the brick paving projecting out from the porch (Appendix B.4.b, Photograph 12). The site is at a lower level compared to the neighboring properties as indicated in photograph 12 and 13 with about 60%-65% of the yard of exposed soil. The high level of PM_{10} is attributed to a high percentage of exposed soil along with the fact that the PM sampler was placed in the direct path of the northwesterly winds. The elevation of the property compared to the west property is lower; hence the fence does not act as a barrier to the NW winds. The presence of a dog is another factor that contributes to the high PM_{10} level. Also pertinent to the study is the weather during the PM sampling period. There was rain at the time the sample was taken. It had rained for 29% of the sampling period with a total rainfall of .27 inches (Appendix D, Table 1). This probably helped in lowering the PM_{10} value, as the soil would be damp and particulates would not be in the atmosphere.

SITE 5

In layout 5 the yard is enclosed within a six feet high solid fence, except on the southeast side where it is a chain-linked fence (Appendix B.5.a). The site is very open and about 70%-75% of the yard is exposed soil. There is free flow of air across the property due to the openness of the property. The high level of PM_{10} is partially attributed to the fact that the PM sampler was in the direct path of the northwesterly winds with vegetation as a backdrop instead of a buffer. The sampler was placed on the southeast side in front of three trees (Appendix B.5.b, Photograph 14). Constant movement on the dirt driveway that runs through the site is another factor contributing to the high level of PM_{10} (Appendix B.5.b, Photograph 14, 15 and 16). Another factor that contributes to a higher PM_{10} level is the presence of three dogs that continually kick up dust from the ground.

SITE 6

There are two yards, one on the south and the other on the west side of layout 6 (Appendix B.6.a). A chain-link fence separates the two yards. The PM level was taken from the west side yard. A six feet high fence runs along the west side (Appendix B.6.b, Photograph 18). About 90% of the yard is covered with exposed soil. This house has the highest PM_{10} level, which can be attributed to the exposed soil and the presence of dogs.

REGION 2 – SE STUDY AREA.

Detailed site evaluation was conducted in six homes. The PM concentration in these homes range from 12.48 $\mu g/m^3$ to a high of 19.88 $\mu g/m^3$ for PM_{10} and 7.46 $\mu g/m^3$ to 9.09 $\mu g/m^3$ for $PM_{2.5}$. Analysis revealed that exposed soil and dirt are the main sources of PM_{10}. The following section describes each site in detail with the help of site layouts and photographs found in Appendix B and Appendix C.

SITE 7

In layout 7 the PM sampler was placed in an enclosed yard on the northwest side of the building (Appendix C.1.a). A three feet high brick fence encloses the yard on the northwest side (Appendix C.1.b, Photograph 19). A dirt driveway is located in front of the yard (Appendix C.1.b, Photograph 20). About 25% of the yard is covered with exposed soil, 50% with irrigated lawn and 25 % with brick paving. The level of PM_{10} would be higher if the low fence, the lawn and the vegetation surrounding the PM sampler were not there because the yard is open to the northwest winds. However, the sample was taken in the fall when the prevailing wind was from the southeast. The low fence might defer the dust at the ground level from rising. Again, there was rain at the time the sample was taken with 1.45 inches in total and it had rained for 18% of the sampling period (Appendix D, Table 2). This probably helped in lowering the PM_{10} value, as the soil would be damp and particulates would not be in the atmosphere. The low fence, wind direction and rain helped in lowering the PM_{10} value.

SITE 8

The yard in layout 8 is located on the south side of the house (Appendix C.2.a). A six feet high concrete block fence encloses it. A major road (Irvington) runs along the south side of the yard. The yard is composed of about 20% exposed soil, 75% weeds and non-irrigated grass, and 10% concrete (Appendix C.2.b, Photograph 21). The shed did not exist when the sample was collected in 1998. The PM sampler was placed where the shed is presently seen in the photograph. The yard is exposed to both the northwest and southeast winds. There was rain at the time the sample was taken. The rain lasted for about half the sampling period (55% of the time) with a total rainfall of .29 inches (Appendix D, Table 2). Again this would have contributed to lowering the PM_{10} value, as the soil would be damp.

SITE 9

In layout 9 the yard is located on the south side of the house (Appendix C.3.a). A six feet high concrete wall encloses it, with about 75 % of the yard covered with exposed soil. An alley runs along the west side of the house and the swimming pool is also located on the west side of the house (Appendix C.3.b, Photograph 23). The fence and the trees along the fence act as a barrier reducing the speed of the wind at ground level. Though there is a high percentage of exposed soil and an alley adjoining the lot, the tall vegetation and solid fence act as strong barriers in maintaining a low PM_{10} level. Rain occurred at the time the sample. It had rained for 33% of the sampling period with a total of .19 inches (Appendix D, Table 2). This could have helped in lowering the PM_{10} value, as the soil would be damp.

SITE 10

In layout 10 the yard is located on the south side of the house (Appendix C.4.a). A six foot high wooden fence encloses it. About 75 % of the yard is covered with exposed soil and vegetation (Appendix C.4.b, Photograph 24, 25 and 26.). The brick paving next to the porch was the location of the PM sampler (Appendix C.4.b, Photograph 24). The high percentage of exposed soil should have given a much higher PM_{10} value, however the fence and tall citric trees mitigated this problem. There was rain at the time the sample was taken. It had rained for 38% of the sampling time with a total of .01 inches only (Appendix D, Table 2). Since there was very little rainfall it is difficult to say if the rain helped in keeping the value low.

SITE 11

As shown in layout 11 the yard is located on the north side on the house (Appendix C.5.a). A six feet high concrete block fence encloses it on the north side and a six feet high wooden fence on the west and east side. An alley runs along the north side of yard. About 25 % of the yard is cover with soil, 25 % is covered with gravel, and 50 % is covered with concrete. The swimming pool is located on the northwest part of the yard (Appendix C.5.b, Photograph 28). Since most of the exposed soil is covered by gravel and half the yard is in concrete with a swimming pool, not much soil is lifted from the ground. The swimming pool also acts as a filtering device and collects the particles that might have been blown in the wind.

SITE 12

As shown in layout 12 the yard is located on the west side of the house (Appendix C.6.a). A six feet high wooden fence encloses the yard with about 40% of the yard covered with exposed soil and 40% with irrigated lawn. The PM sampler was placed under the porch (Appendix C.6.b, Photograph 29). Photograph 30 shows the northwest part of the yard and photograph 31 shows the southwest part of the house where the swimming pool is located (Appendix C.5.b). Most of the northwest and southwest part of the yard was covered with exposed soil at the time the sample was collected. The swimming pool was under construction during the sample period. The high PM_{10} value was affected by the construction of the pool, the exposed soil surrounding the porch area and also the dust collected from under the porch. The lawn and fence helps in mitigating the PM_{10} level to a large extent.

SITE SPECIFIC ANALYSIS: FINDINGS.

The case studies were analyzed and compared with the help of figures. The analysis was based on a set of assumptions. The first assumption is that the value of PM_{10} increases with increase in the percentage of percentage of exposed soil. This is based on the theory that dirt or disturbed ground is a main source for particulate. The second assumption is that the proximity of unpaved dirt roadway increases the PM_{10} values. The third assumption is that vegetation helps in mitigating the level of particulates in the air. The ground vegetation helps in holding the soil and thereby the ground is not disturbed when the wind blows. The taller vegetation acts as a barrier to the air borne particulates. The fourth assumption is that the exposure of the yard to the wind is depended on the openness of the yard. If the yard is more open it is subjected to higher wind flow. Finally, The presence of rain during the sampling period could have helped in reducing the PM_{10} value, as the soil would be damp.

NORTHWEST SITES

FIGURE 2: YARD COVER

Figure 2 shows that the value of $PM_{10}\mu g/m^3$ and $PM_{2.5}\mu g/m^3$ increased with decrease in aggregate yard cover. The figure shows that Site 1 had the lowest value for exposed soil and Site 6 had the highest value. This supports the assumption that the more area of exposed soil, the higher the $PM_{10}\mu g/m^3$ value. Site 1 had a high gravel content that helped in keeping the PM_{10} level low. Site 2 had high lawn coverage over most of the yard that played a significant role in keeping the value of PM_{10} level low. The percentage of exposed soil in Site 3 doubled over that of Site 2 causing a drop in the aggregate value. The percentage of concrete and lawn cover was very low to mitigate the PM_{10} value. A similar trend was seen in Site 4, where the aggregate cover was made of brick. In Site 5 the aggregate dropped further thereby increasing the PM_{10} value. Site 6 also had a low aggregate value. Here the high percentage of exposed soil played a significant role in the high PM_{10} value.

FIGURE 3: VEGETATION TYPE

Figure 3 shows the relationship between vegetation type and PM data. The vegetation data was based on the number of trees, plants and shrubs in each yard; hence it was difficult to estimate the role of each individual type of vegetation at the micro level. In most sites the height of the vegetation was not tall enough to act as a barrier to the wind. However, a case by case evaluation revealed that vegetation does help in mitigating the level of particulates in some of the sites. In all six sites except the second site, there seem to have been an even distribution of trees at a scale of 2 and shrubs at a scale of 4.

Site 1 had the highest combined vegetation (trees, shrubs and plants) that is mostly native, and on the other extreme Site 6 had a low combined vegetation. If the vegetation is combined with the aggregate yard cover from Figure 2 we can see that Sites 1 and 2 have a low PM_{10} value. On the other hand, though the vegetation scale for sites 4 and 5 was similar to Sites 1 and 2 the percentage of exposed soil (seen from graph) was more, causing an increase in PM_{10} value.

FIGURE 4: ROAD AND PAVING TYPE

Figure 4 shows the relationship between road type and PM values. The figure is scaled such that, the higher any road type is scaled the higher it is a source for particulates. The aggregate showed that sites 2, 3, 5 and 6 had unpaved/dirt roadways. Sites 2 and 3 had alleys that have either weeds or some vegetation cover. Sites 5 and 6 had the highest PM_{10} values and neither of them had any type of vegetation. Individual examination revealed that the unpaved dirt driveway in Site 5 runs along the yard and in Site 6 runs through the site, causing the high PM_{10} value. Hence, these unpaved/ dirt roadways do influence the PM_{10} value.

FIGURE 5: OPENNESS OF YARD TO WIND FLOW

Figure 5 shows the openness of the yard to wind flow. Everything been constant, the more open the yard is the more it is subjected to wind flow and hence a higher PM_{10} value. This figure showed that both Site 1 and Site 5 had a higher wind exposure. But Site 1 had less exposed soil and Site 5 had a much higher percentage of exposed soil. Moreover, Site 5 had a dirt driveway running across the yard in the path of the wind. This could have been a factor contributing to the difference in PM_{10} levels. Though Site 6 had a medium exposure to the northwest wind and a low exposure to southwest wind it had the highest PM_{10} value. This can be attributed to the fact that the site had a high percentage of exposed soil, a low combined vegetation cover, and the presence of a dirt driveway in the path of the wind.

FIGURE 6: INFLUENCE OF DOGS

Figure 6 shows that presence of dogs could be another factor influencing the PM_{10} values. This was based on the assumption that the dogs might kick up dust. Since nothing was known about the breed and age of the dogs, it was difficult to understand the nature and habits of the dogs. This information might have been used to form a more vivid picture of the effect of dogs on the PM_{10} values. Just based on the absence or presence of the dogs and also the number of dogs in a household, we can see from the figure that Sites5 and 6 had more dogs. The PM_{10} levels and the percentage of exposed soil were the highest in these two sites. This means that the presence of dogs elevate the PM_{10} level when coupled with the percentage of exposed soil.

FIGURE 7: OTHER VARIABLES

Figure 7 shows the presence of a barbecue grill, fireplace in almost every house and a swimming pool in only the first site. A case by case study showed that the presence of a swimming pool helped in mitigating the PM_{10} value by acting as a filtering device. The use of the barbecue grill and fireplace affects the $PM_{2.5}$ value. Since the actual duration of the use was not known it was difficult to estimate the actual effect on the $PM_{2.5}$ value.

FIGURE 2: YARD COVER

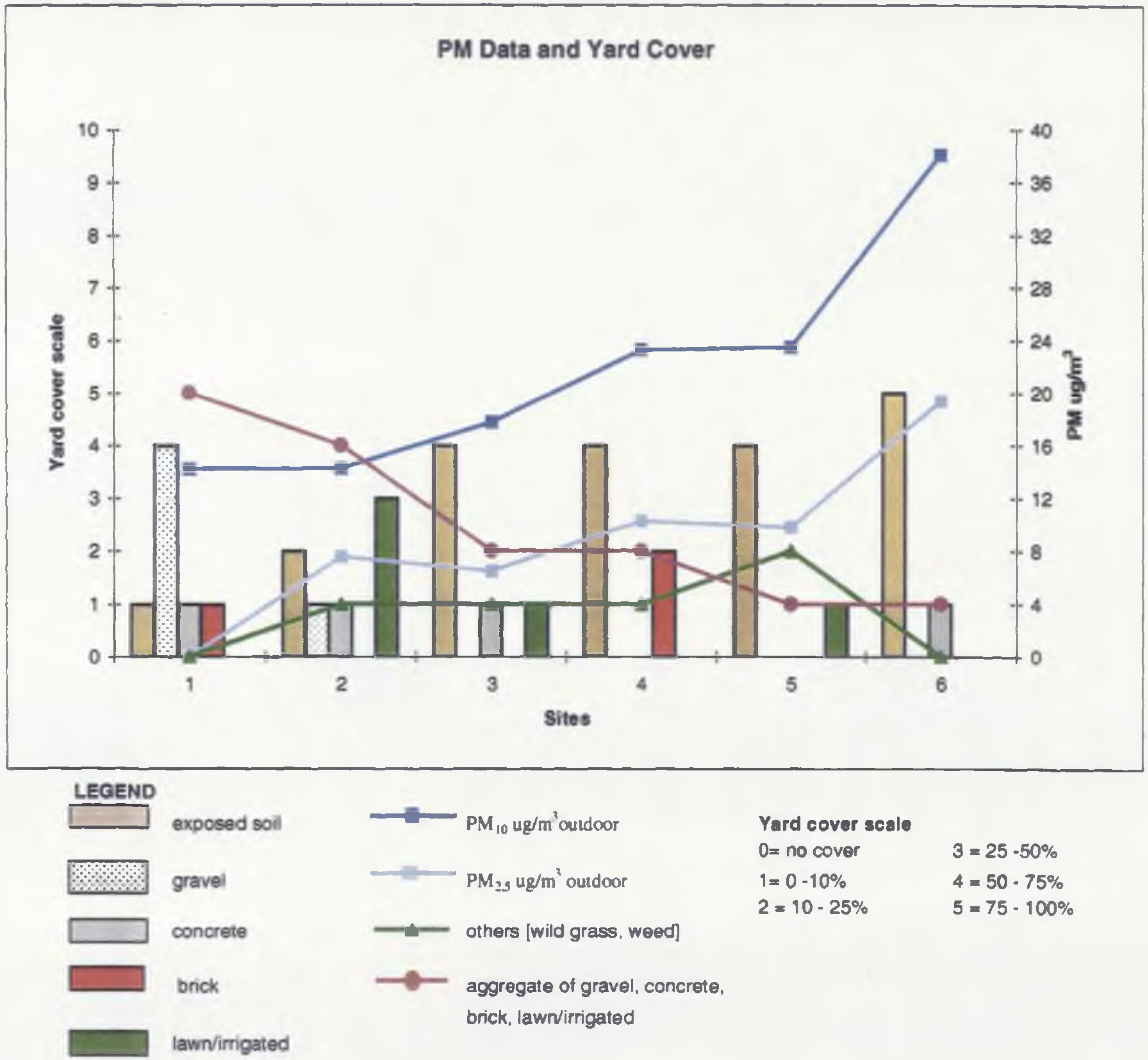
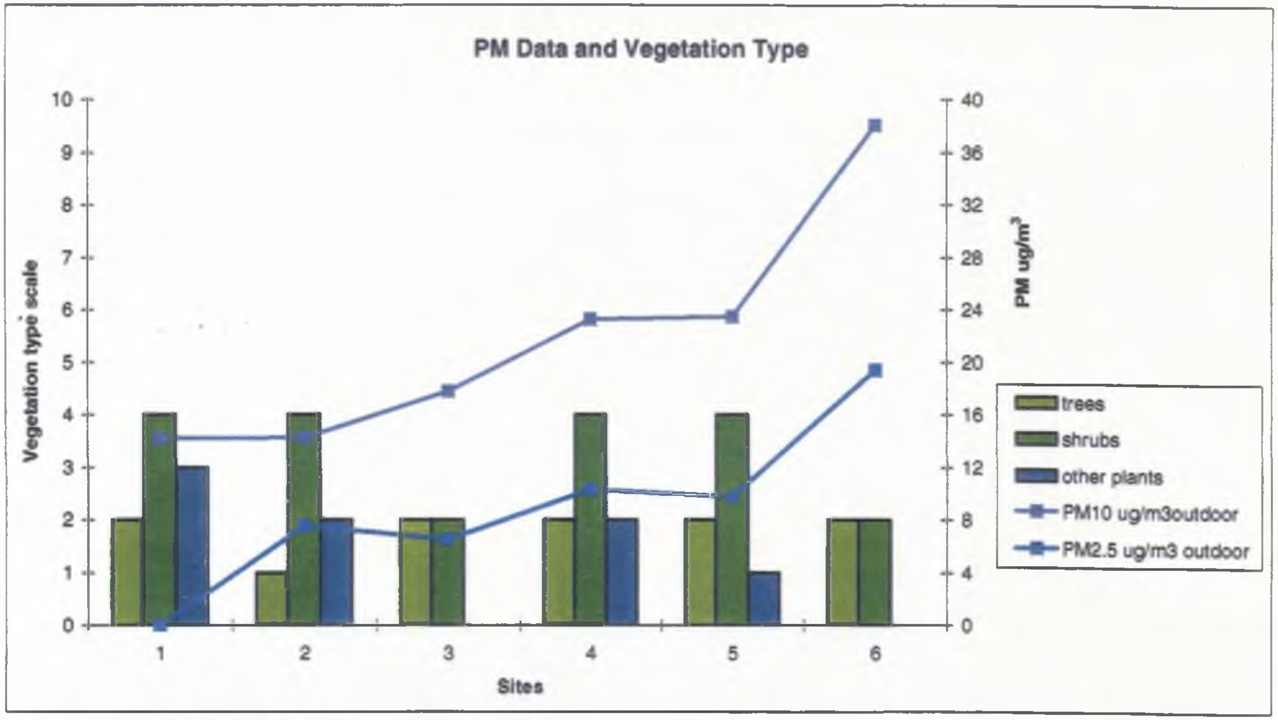


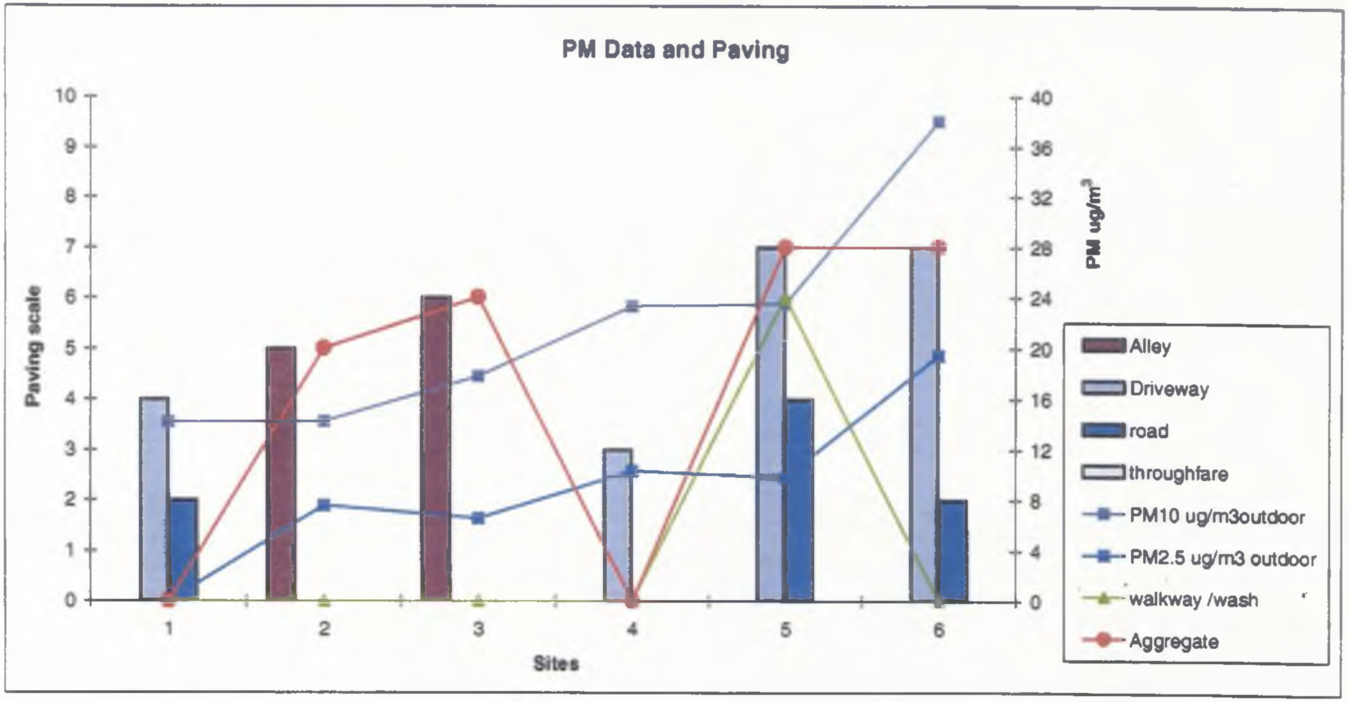
FIGURE 3: VEGETATION TYPE



Vegetation type scale
no:of Trees, shrubs, plants

0 = no veg	2 = 4- 7	4 => 10
1 = 1- 3	3= 8 - 10	

FIGURE 4: ROAD AND PAVING TYPE

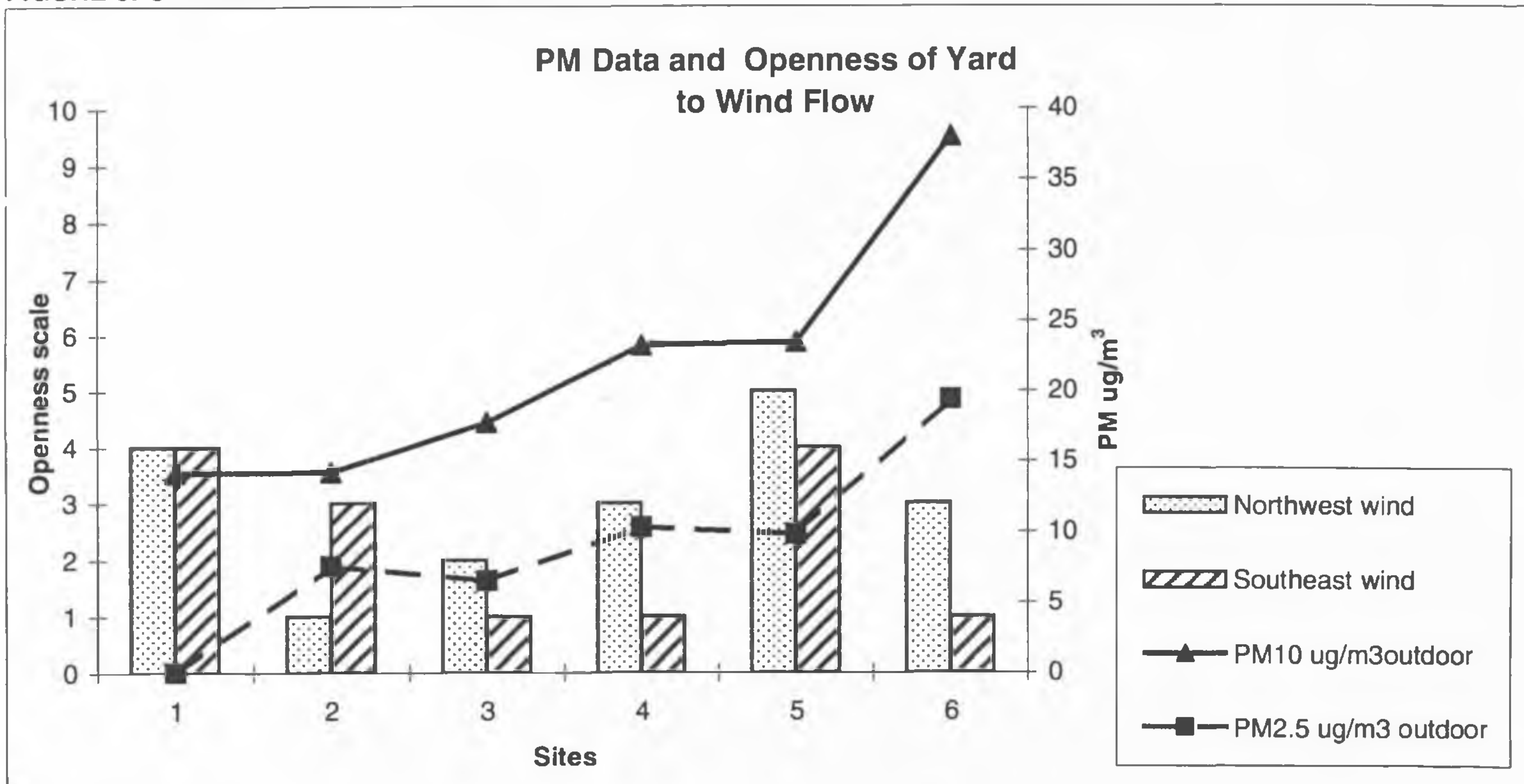


Paving scale

paved / weeds =1
paved/ tar = 2
paved / brick =3
unpaved / gravel =4
unpaved/dirt/weed =5
unpaved /dirt/ veg = 6
unpaved / dirt =7

The aggregate of unpaved dirt, unpaved/dirt/veg and unpaved/dirt/weed are taken.

FIGURE 5: OPENNESS OF YARD TO WIND FLOW



Openness scale:

0 = no flow	3 = medium
1 = low	4 = medium - high
2 = low - medium	5 = high

FIGURE 6: INFLUENCE OF DOGS

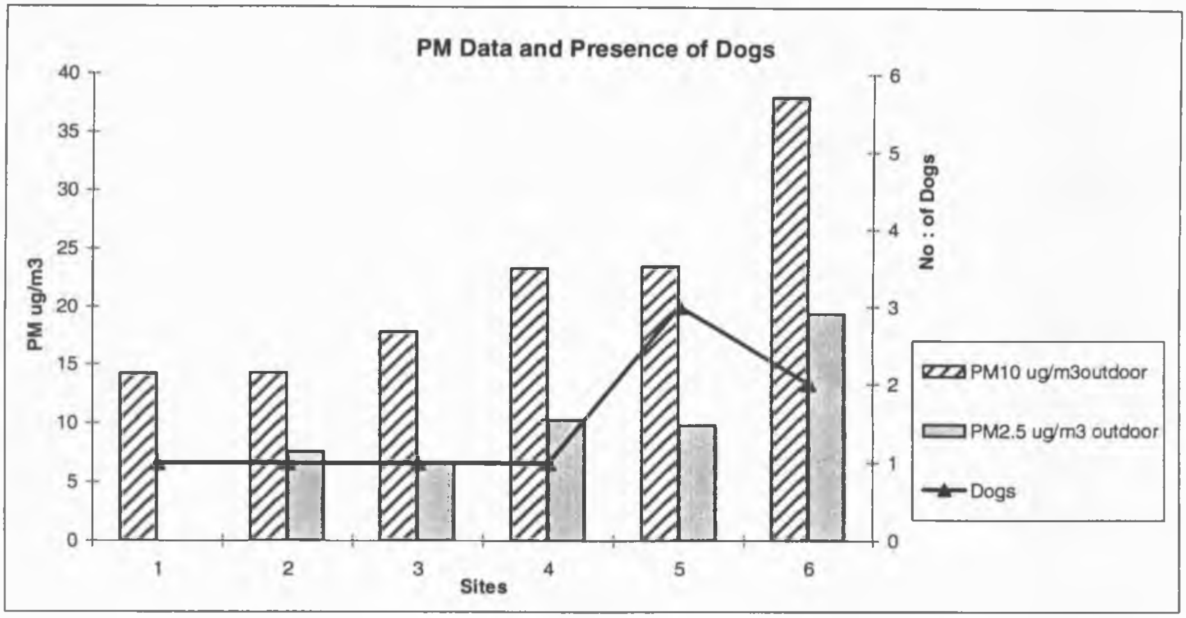
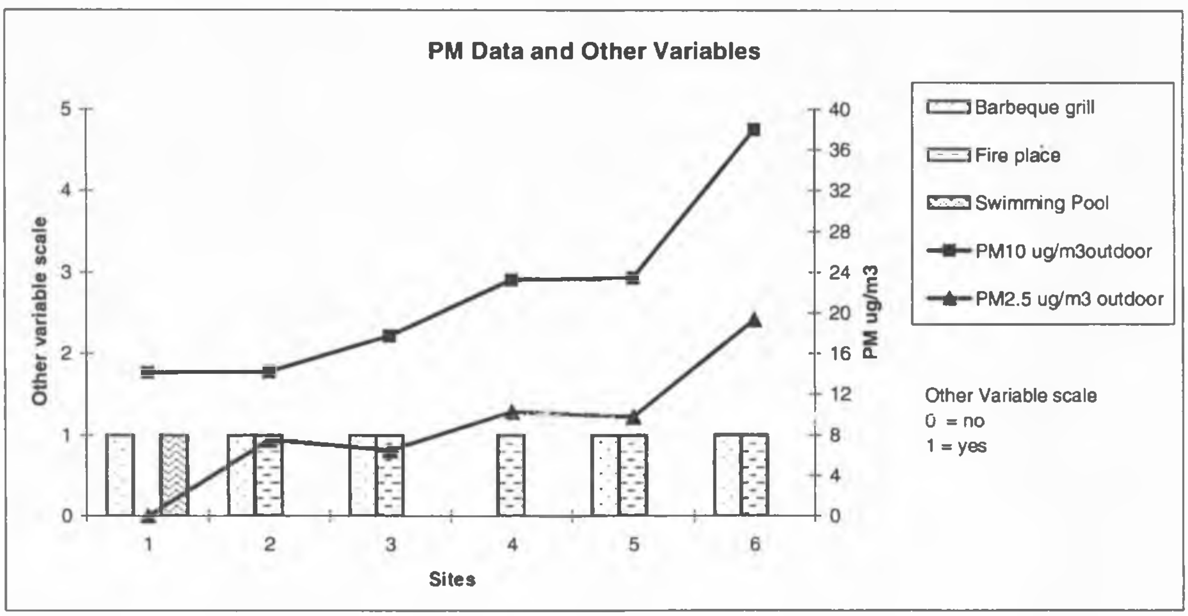


FIGURE 7: OTHER VARIABLES



SOUTHEAST SITES:

FIGURE 8: YARD COVER

Figure 8 shows that the aggregate yard cover did not affect the PM_{10} levels. The figure shows that Site 7, 8 and 11 had the lowest value for exposed soil and Sites 9 and 10 had the highest value. In Site 7 the lawn covered most of the exposed soil and might have helped in mitigating the PM level. The aggregate ground cover value dropped down in Site 8. This should have theoretically indicated a high PM_{10} value, but this is not the case. One explanation would be the effect of rain during the sampling period (Appendix D, Table 2); the other would be the high percentage of wild grass or weeds. Site 9 and 10 had the highest percentage of exposed soil, but the sites fall in the middle of the PM line. One possibility would have been the effect of rain and the other the presence of vegetation as discussed in the next paragraph. Though Site 11 was on the upper end of the PM_{10} level, the presence of gravel and concrete would have helped in mitigating the PM level. The presence of a high percentage of lawn cover in the last site helped in mitigating the PM_{10} level.

FIGURE 9: VEGETATION TYPE

Figure 9 shows the vegetation type. The vegetation data was based on the number of trees, plants and shrubs in each yard; hence it was difficult to estimate the role of each individual type of vegetation at the micro level. However, a case by case evaluation revealed that vegetation did help in mitigating the level of particulates in some of the sites. The distribution of vegetation over the six sites was uneven. Sites 9, 10, and 12 showed a high number of trees and also the highest combined vegetation (trees, shrubs, and plants).

This might have played a significant role in mitigating the PM level especially in Sites 9 and 10.

FIGURE 10: ROAD AND PAVING TYPE

Figure 10 shows the relationship between road type and PM values. The figure is scaled such that, the higher any road type is scaled the higher it is a source for particulates. The aggregate showed that Sites 7, 9, 10, 11and 12 had unpaved/dirt roadways. Individual examination revealed that the unpaved dirt driveway in Site 7 runs along the yard, but was fenced off by vegetation and a low brick fence. These two factors might have helped lower the PM_{10} level. In Sites 9 and 10 the tall vegetation acted as barriers to the wind, thereby lowering the PM_{10} levels.

FIGURE 11: OPENNESS OF THE YARD TO WIND FLOW

Figure 11 shows the openness of the yard to wind flow. Everything been constant, the more open the yard is the more it is subjected to wind flow and hence a higher PM_{10} value. The graph showed that Sites 7,8,and11 had a medium to high wind exposure. Site 7 and 8 and 11 had less exposed soil. But Site 11 had low exposed soil with high wind exposure, thereby increasing the possibility of a high PM_{10} level as seen in the figure. This high level could have also been caused by the presence of the unpaved dirt alley.

FIGURE 12: INFLUENCE OF DOGS

Figure 12 shows that presence of dogs could be another factor influencing the PM_{10} values. This is based on the assumption that the dogs might kick up dust. Since nothing was known about the breed and age of the dogs, it was difficult to understand the nature and habits of the dogs. This information might have been used to form a more vivid picture of the effect of dogs on the PM_{10} values. Just based on the absence or presence of the dogs and also the number of dogs in a household, we can see from the figure that only Site 8 had more dogs compared to Site 9, 11 and 12. Nothing much can be derived about the effect of dogs on PM level.

FIGURE 13: OTHER VARIABLES

Figure 13 shows the presence of a barbecue grill, swimming pool and fireplace. The use of the barbecue grill and fireplace affects the $PM_{2.5}$ value. Since the actual duration of the use was not known, the actual effect of the grill and fireplace on the $PM_{2.5}$ level was not known. A case by case study of Site 11 showed that the presence of a swimming pool helped in mitigating the PM_{10} value by acting as a filtering device.

FIGURE 8: YARD COVER

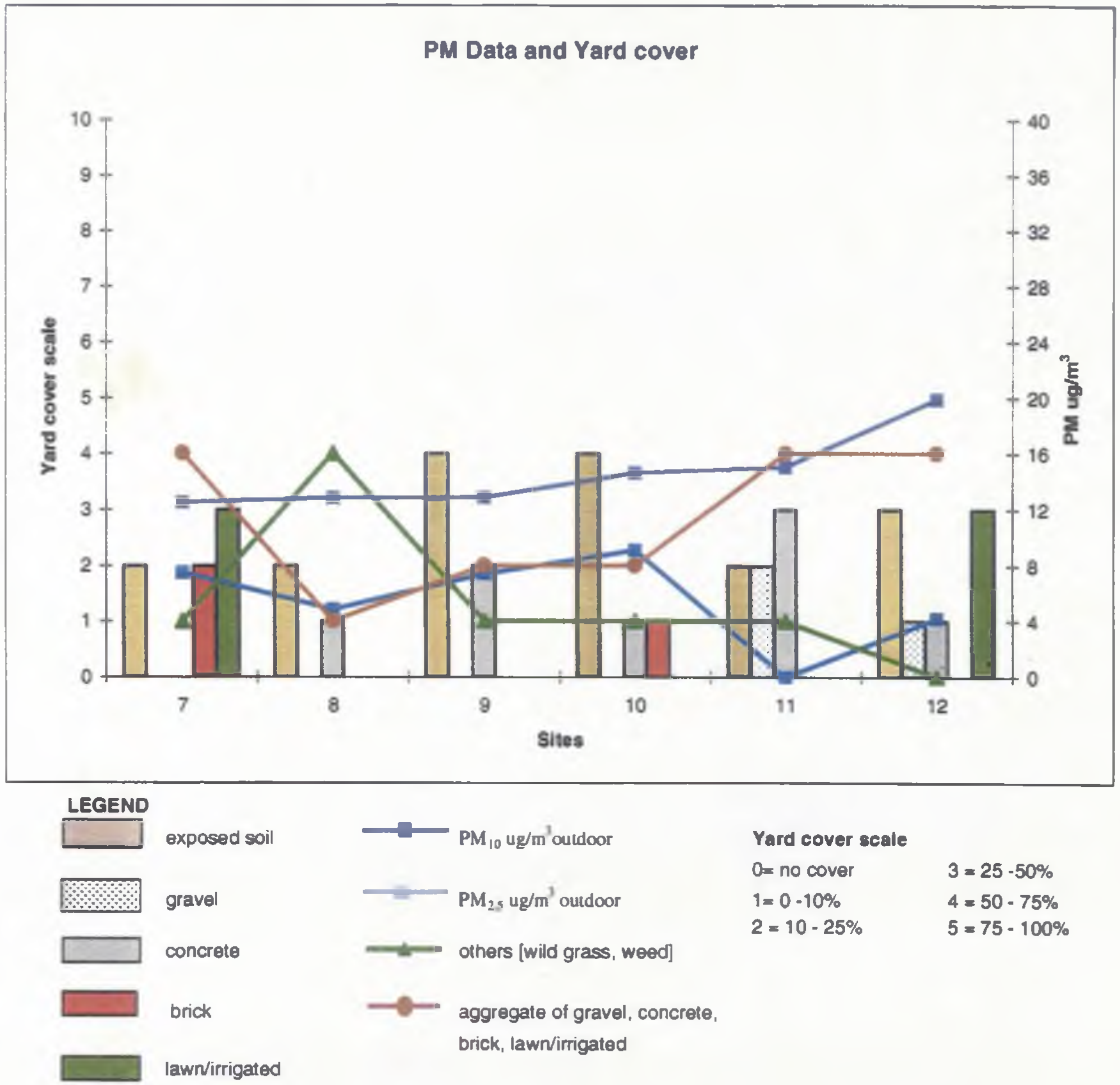
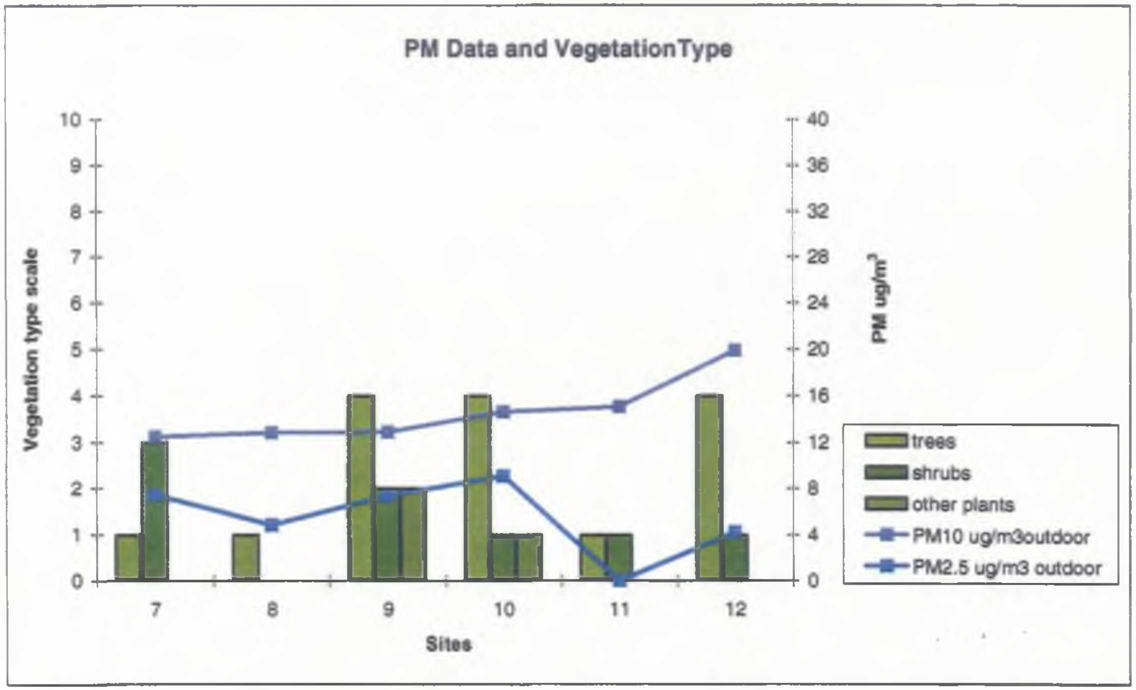


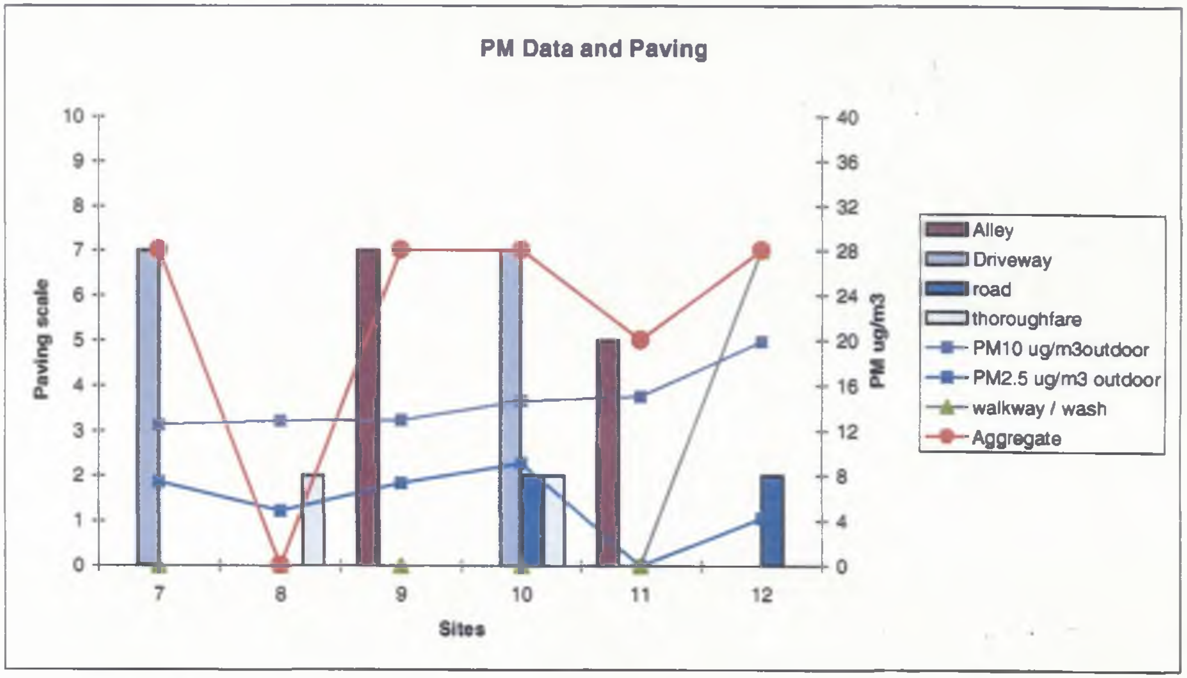
FIGURE 9: VEGETATION TYPE



Vegetation type scale
no:of Trees, shrubs, plants

0 = no veg	2 = 4- 7	4 => 10
1 = 1- 3	3= 8 - 10	

FIGURE 10: ROAD AND PAVING TYPE

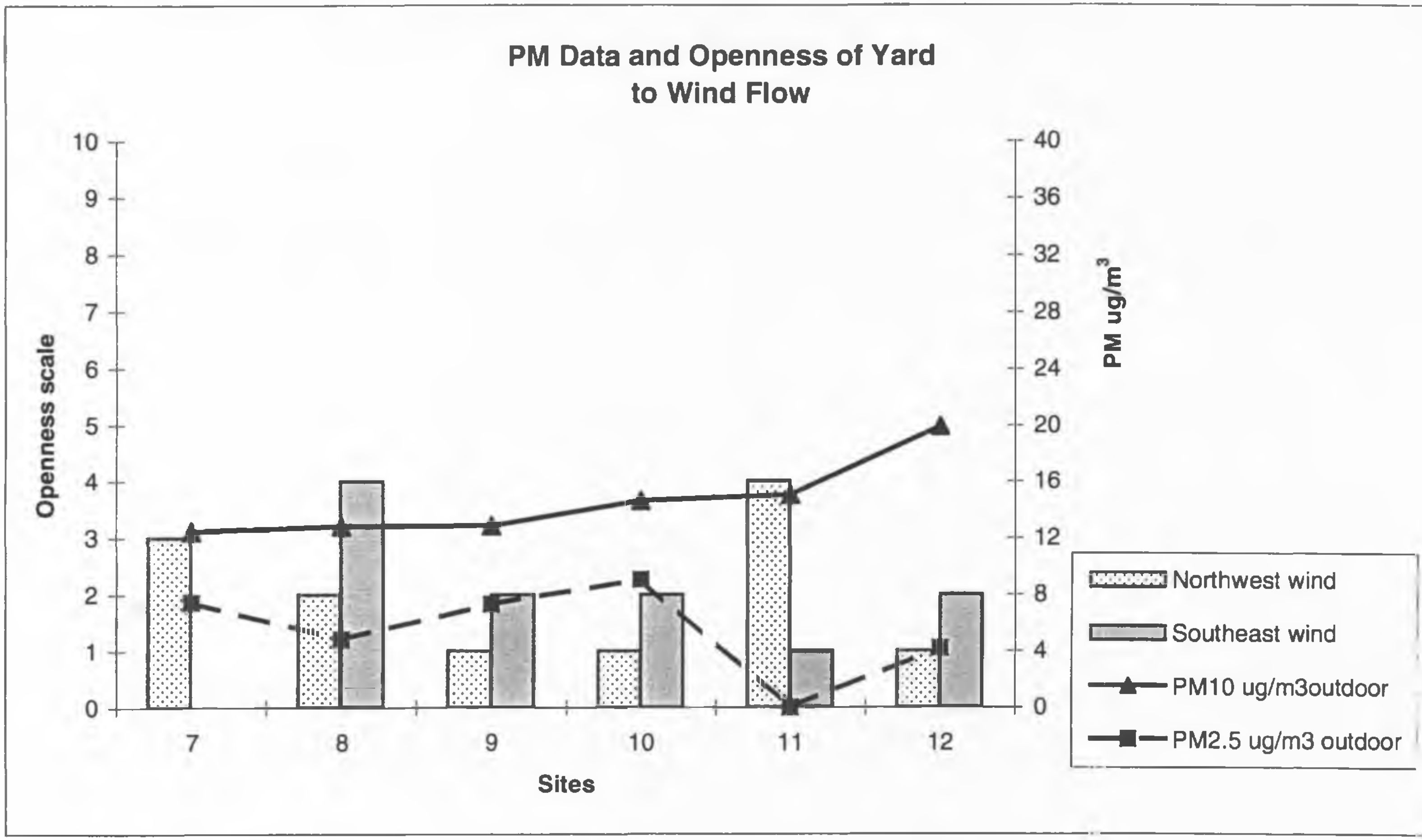


Paving scale

paved / weeds = 1
paved / tar = 2
paved / brick = 3
unpaved / gravel = 4
unpaved /dirt / weeds = 5
unpaved / dirt / veg = 6
unpaved / dirt = 7

The aggregate of unpaved dirt, unpaved/dirt/veg and unpaved/dirt/weed are taken.

FIGURE 11:OPENNESS OF YARD TO WIND FLOW



Openness scale:

0 = no flow	3 = medium
1 = low	4 = medium - high
2 = low - medium	5 = high

FIGURE 12: INFLUENCE OF DOGS

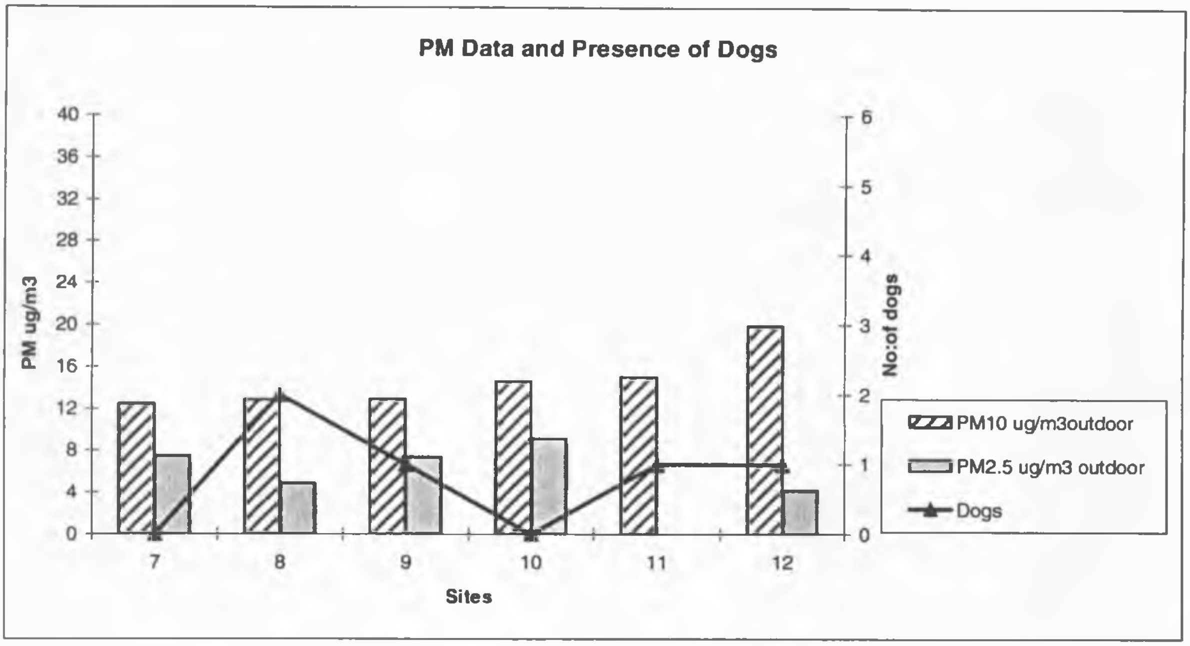
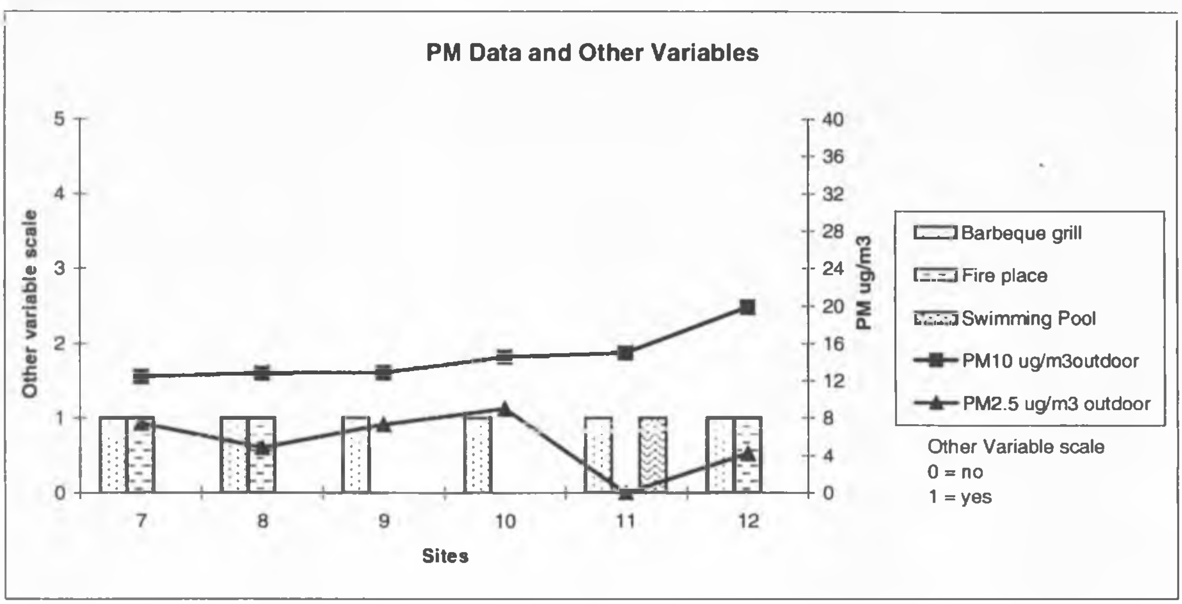


FIGURE 13: OTHER VARIABLES



COMPARATIVE ANALYSIS:

This section compares the design/ landscape variables in the two study areas against the PM_{10} and $PM_{2.5}$ values. Before discussing the variables it is important to compare the range of the PM values in both areas. The northwest study area has a wider range of PM_{10} levels compared to the southeast study area. The southeast range fits in the lower half of the northwest study area. This broad range gives a better scope for analyzing the various variables.

The northwest study supported the assumption that the more area of exposed soil there was, the higher the PM_{10} value. This can be seen in figure2 where the PM value increased with increase in exposed soil. The southeast side, on the other hand, did not show a distinctive correlation between yard cover and PM_{10} values. This was attributed to the effect of rain in the southeast area (Appendix D, Table 2) where it rained at four sites at least once during the sampling week. The detailed analysis in both areas showed that the presence of yard cover such as gravel, concrete or brick helped in lowering the PM_{10} level.

Although, it was difficult to show the usefulness of vegetation in mitigating the PM_{10} levels, some of the sites did show that it was possible. This was specifically seen in the southeast area where tall trees acted as buffers. It is however important for the trees to be placed in the right location against the wind direction instead of along the path. This was evident in Sites 9 and 10 where the trees acted as buffers (Figure 9 and Appendix C Photograph 23, 26). The opposite phenomenon was seen in Site 5 (Appendix B Photograph 14).

The theory that unpaved roads are a source of PM_{10} was to some extent supported in Figures 4 and 10. This was seen in Sites 5, 6, 11 and 12. Figure 10 also showed that Sites 9 and 10 had unpaved dirt alley and driveway, but had a low PM_{10} level. In this case there were other factors such as rain and vegetation that influenced the PM_{10} level. It was seen that unpaved dirt alleys or driveways adjacent to the site acted as sources for particulates.

The openness of the yard is another important factor in determining the PM level that can be trapped in the yard. The openness of the yard relates to the position of the fence all around the yard. All 12 sites had fence around the yard. If the site had a high openness index, it meant that it was open to medium to high wind flow. The openness factor was always looked at with respect to the wind pattern, yard cover and vegetation. Figures 5 and 11 showed that Site 1, 5, 8 and 11 had a medium to high exposure to wind. But in Sites 1 and 11 the presence of a high yard cover helped in mitigating the PM_{10} level.

It was difficult to justify that the presence of dogs can cause a high PM_{10} level if there was a medium to high percentage of exposed soil. Only few sites such as 5 and 6 showed a possible correlation where the percentage of exposed soil was high and there were two or more dogs. Also these two sites had no rain and hence support the theory of possible correlation. In the southeast area Site8 had a high percentage of exposed soil and had two dogs, but a low PM_{10} value. This could have been different if rain had not occurred during that time.

The presence of a swimming pool in Site 1 and site 11helped in mitigating the PM_{10} value by acting as a filtering device. Since only two sites has a swimming it was difficult to gauge the actual effect of the presence of a pool. The relationship of the barbecue grill and fireplace to the $PM_{2.5}$ value needed more data with respect to the duration of use, the number of times used during the sample period. Hence no conclusion was arrived at with regard to the effect of the grill and fireplace on the $PM_{2.5}$ value.

Another important factor that played a significant role in the study was the weather during the PM sampling period. The presence of rain during the sampling period helped in lowering the PM_{10} value, as the soil would be damp and particulates would not be in the atmosphere. This factor was seen in many sites in both study areas. In the northwest area Sites 1, 2 and 4 and in the southeast Sites 7,8,9 and 10 had rain. The major effect of this rain was seen in Site 9, and 10 where the percentage of exposed soil was high (Table 2 Appendix D).

CONCLUSION AND PLANNING POLICY IMPLICATION

The analysis of all 12 sites revealed that most of the assumptions and theory (as indicated in the beginning of the summary of the case studies in Chapter 3) were applicable to the northwest area. In sites unaffected by rainfall, clear trends were evident that require further investigation. Results in this study are equivocal. However, it is important to note that this conclusion is based on a limited number of sites and I have demonstrated that some valid micro-environmental level points can still be drawn that might help in mitigating the PM levels at the micro-level. Since zoning and subdivision regulations are enacted to control the design of neighborhoods, some planning policies based on the results of this study should be considered before design standards are set.

Cluster development helps in mitigating PM_{10} levels. Results from this study suggested that PM_{10} values were reduced because of the use of paving over exposed soil.

The study showed that sites in higher density areas had lower PM_{10} values. However, $PM_{2.5}$ is increased by traffic and human activities such as barbecue grilling, automobile driving, and lawn mowing. Cluster development will increase local levels of $PM_{2.5}$. To mitigate $PM_{2.5}$ levels such strategies as, restriction on the use of gasoline/kerosene lawn mowers, limiting the through traffic to residents only, and allowing only an optimum number of residential units in the cluster development should be used or any benefits from lower levels of PM_{10} will be offset by increases in the $PM_{2.5}$ levels.

At a micro-level (within the sites), ground yard cover should be encouraged. This study showed, especially in the northwest study area, that the use of ground yard cover lowered the PM_{10} value, since exposed soil/dirt was a major source. Some of the covers that were seen to be effective were gravel, lawn, ground vegetation, concrete and brick.

The use of vegetation as a buffer should be encouraged. The study showed that sites that had vegetation (trees and shrubs) had a lower PM_{10} level. These buffers should be placed so that they block some of the wind flowing into and out of the yard. Berm could be used instead of fences to act as buffers for the yard. At a regional level, these buffer strips should be placed between the residential areas and major highway or roads, light and heavy industries, and washes. These measures would ensure that the wind blowing over these potential sources of PM_{10} and $PM_{2.5}$, are filtered by the vegetation before blowing over the residential areas.

At a site specific level the use of low water consuming vegetation (native vegetation) should be encouraged and incorporated in every landscape design and review. The use of low consuming vegetation is important in places like Tucson.

However, it is important to note that, PM_{10} values may increase due to low moisture content in the ground.

Paving of roads and alleys should be encouraged. Results from this study showed that sites that had unpaved alleys or driveways adjacent to the yard had a high PM level. This can be avoided by encouraging officials to pave and maintain alleys and public roads. Within subdivisions or individual lots, the use of gravel or paved driveways and roads should also be encouraged.

While there may be more implications for planning strategies that can be drawn from more research on controlling air pollution at a micro-level, these policy implications are a significant means of addressing the problem. It is important to note that planners should be involved in health studies such as utilized in this report. Good data sets relating to health issues can answer many planning questions. If such work is done, it could be possible to mitigate particulate level at a micro-level.

REFERENCE

Bennett, A. ed. 1988. *Air Quality in Arizona.* Center for Advanced Research in Transportation, Arizona State University.

Caldwell, R. ed. 1971. *Air Pollution in Tucson.* Tucson: Tucson Advisory Commission on Air Pollution.

Craxford, S. R., and Weatherly, P. M. 1966. "Planning for Clean Air". *Journal of Town Planning Institute*. Vol: 52.

Department of Environmental Quality. 1988. *Annual Data Summary: Air Quality in Tucson Arizona.* Pima County, Arizona.

___________________. 1995. *Annual Data Summary: Air Quality in Pima County.* Pima County, Arizona.

Duffield, R. M. and Jones, D. W. 1990. *Plants for Dry Climates.* Los Angeles, Calafornia: HP Books Publications.

Environmental Protection Agency (EPA). 1998. *Fact Sheet.* World Wide Web, http://ttnwww.rtpnc.epa.gov. University of Arizona: Internet.

____. 1998. *Indoor and Outdoor Air Pollution.* http://www.lbl.gov/education /ELSI/Frames /pollution-main-f.html. Tucson: University of Arizona: Internet

Fogiel, M. ed. 1978. *Modern Pollution Control Technology.* New York: Research and Education Association.

Geddes, R. ed. 1997. *Cities in Our Future: Growth and Form, Environmental Health and Social Equity.* Covelo, California: Island Press.

Hough, M. 1995. *Cities and Natural Process.* London, England: Routledge Publications.

Lebowitz, M. D. 1993. *Study Design (Revision of 31 Dec. 1993*). EPA NHEXAS Cooperative agreement.

Lowe, C. H. 1972. *The Vertebrates of Arizona.* Tucson, Arizona: University of Arizona Press.

Norman, L. and Wood, C. M. 1972. "Planning and Pollution." *Journal of the Royal Town Planning Institute*, Vol. 58, P. 153.

Puget Sound Air Pollution Control Agency. 1998. *All About Air.* http://www.psapcca.org/airqual.html. University of Arizona: Internet.

Quakenboss, J. J. 1991. "Exposure Assessment Approaches to Evaluate Respiratory Health Effects of Particulate Matter and Nitrogen Dioxide." *Journal of Exposure Analysis and Environmental Epidemiology*, Vol. 1, P 83.

Rydell, P. C. and Schwarz, G. 1968. "Air Pollution and urban form: A review of current literature." *Journal of the American Institute of Planners*, Vol. 34, P. 115.

Sauerwein, C. H. 1980. *An Application of Landsat Digital Data To Air Quality Planning In The Tucson Area.* Master's Thesis, Tucson, Arizona: University of Arizona.

Steenbergh, W. 1977. Preliminary *Ecological investigation of Natural Community Status Organ Pipe Cactus National Monument.* Tucson, Arizona: University of Arizona.

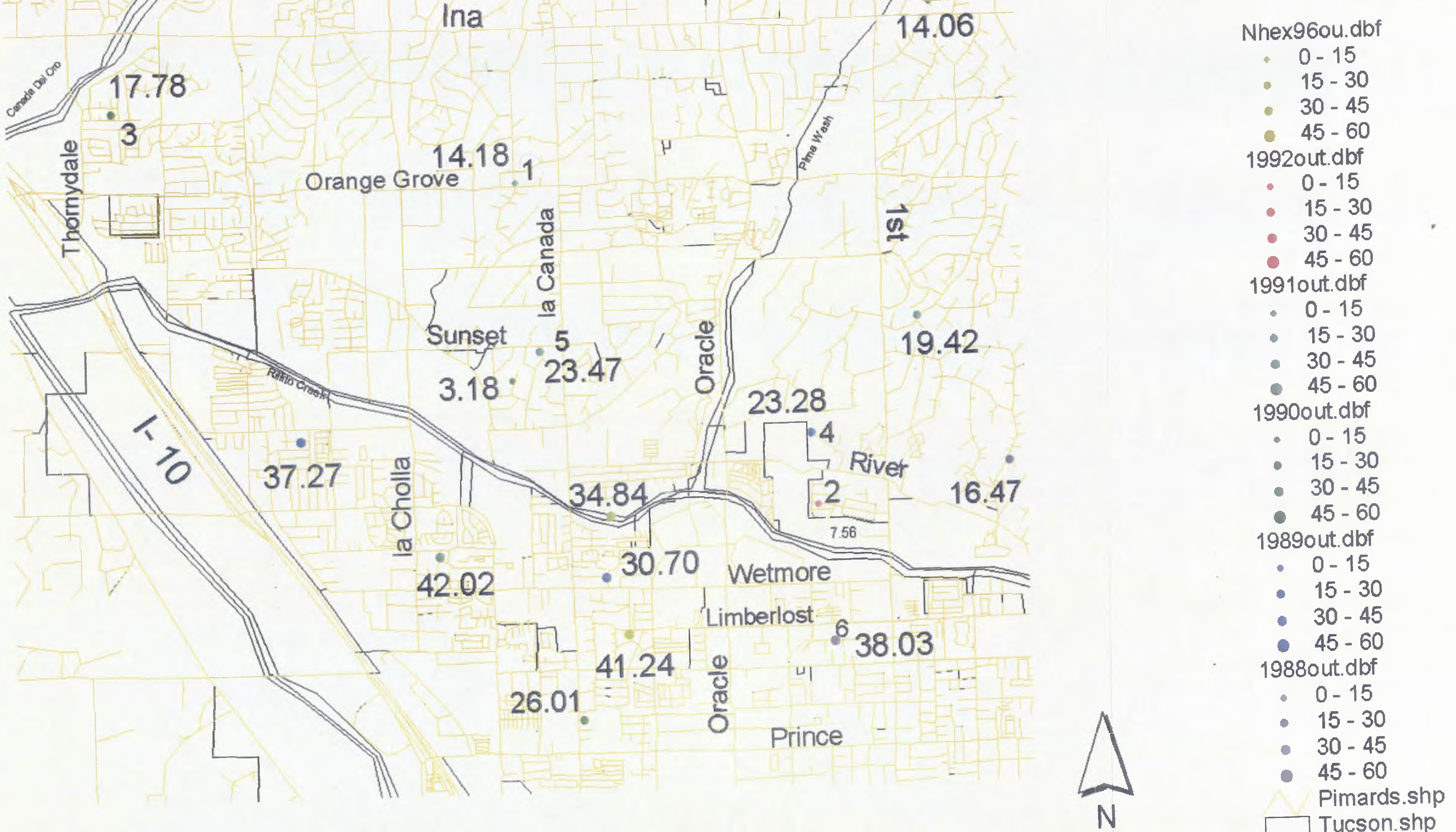
White, R. R. 1994. *Environmental Management: Environmental Change and Urban Design.* New York, NY: John Wiley & Sons Ltd.

Wood, C.M. 1990. "Air Pollution Control by Land Use Planning Techniques: A British-American Review." *International Journal of Environmental Studies*, Vol.35, P. 233.

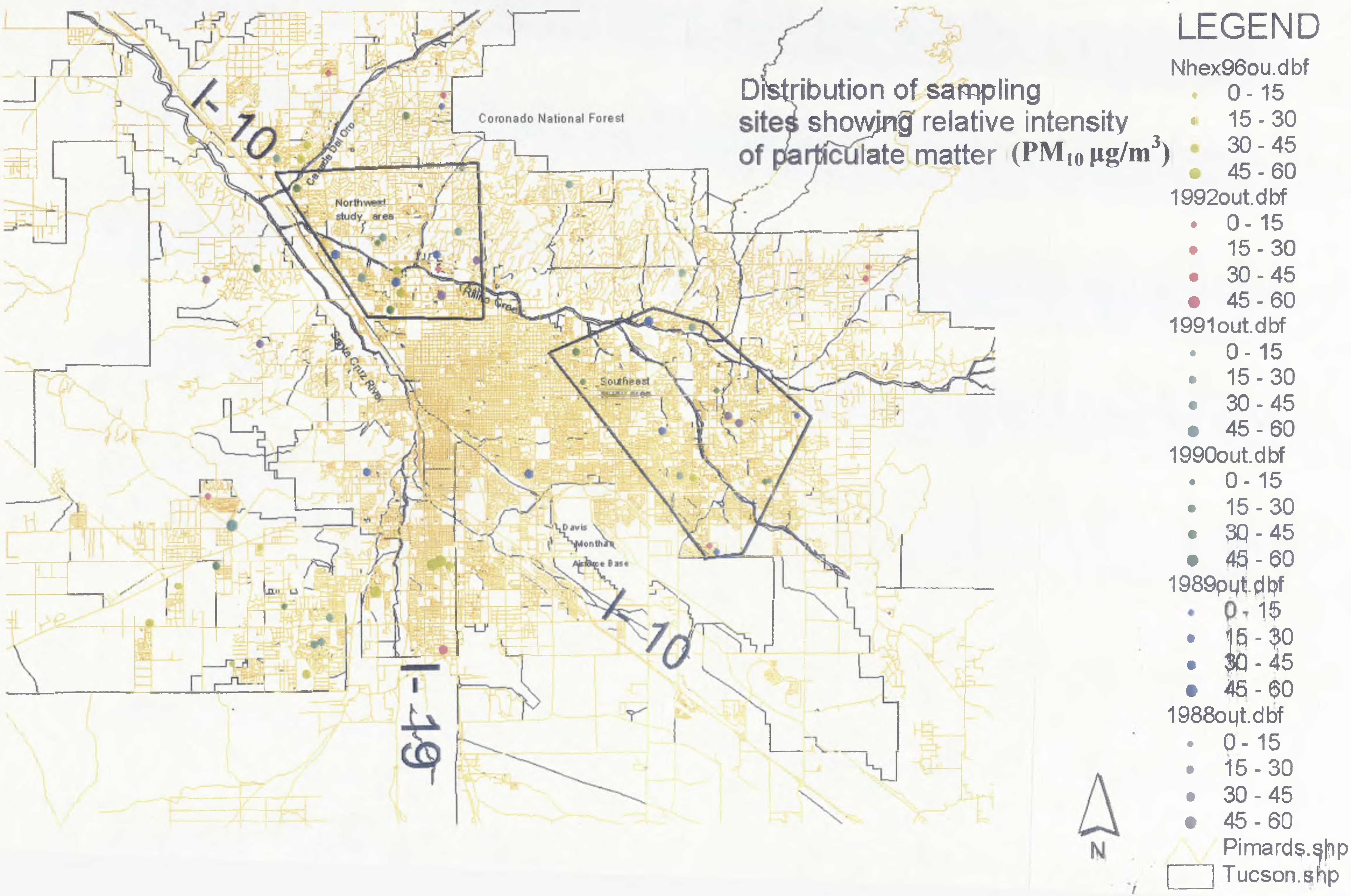
APPENDIX A : MAPS

1. MAP OF TUCSON

PM_{10} µg/m³ Distribution Northwest Study Area

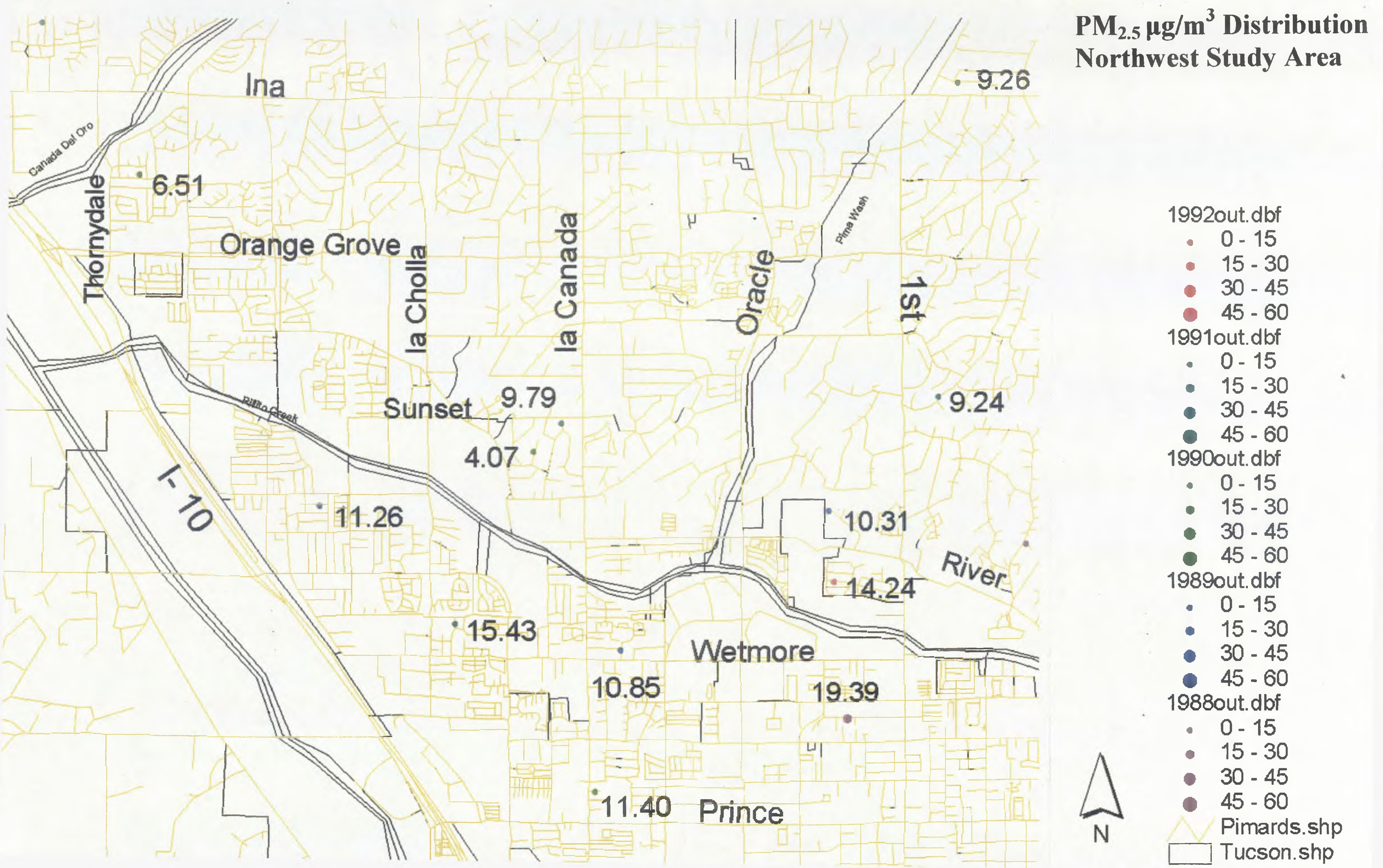


2. NORTHWEST STUDY AREA (PM_{10} $\mu g/m^3$)



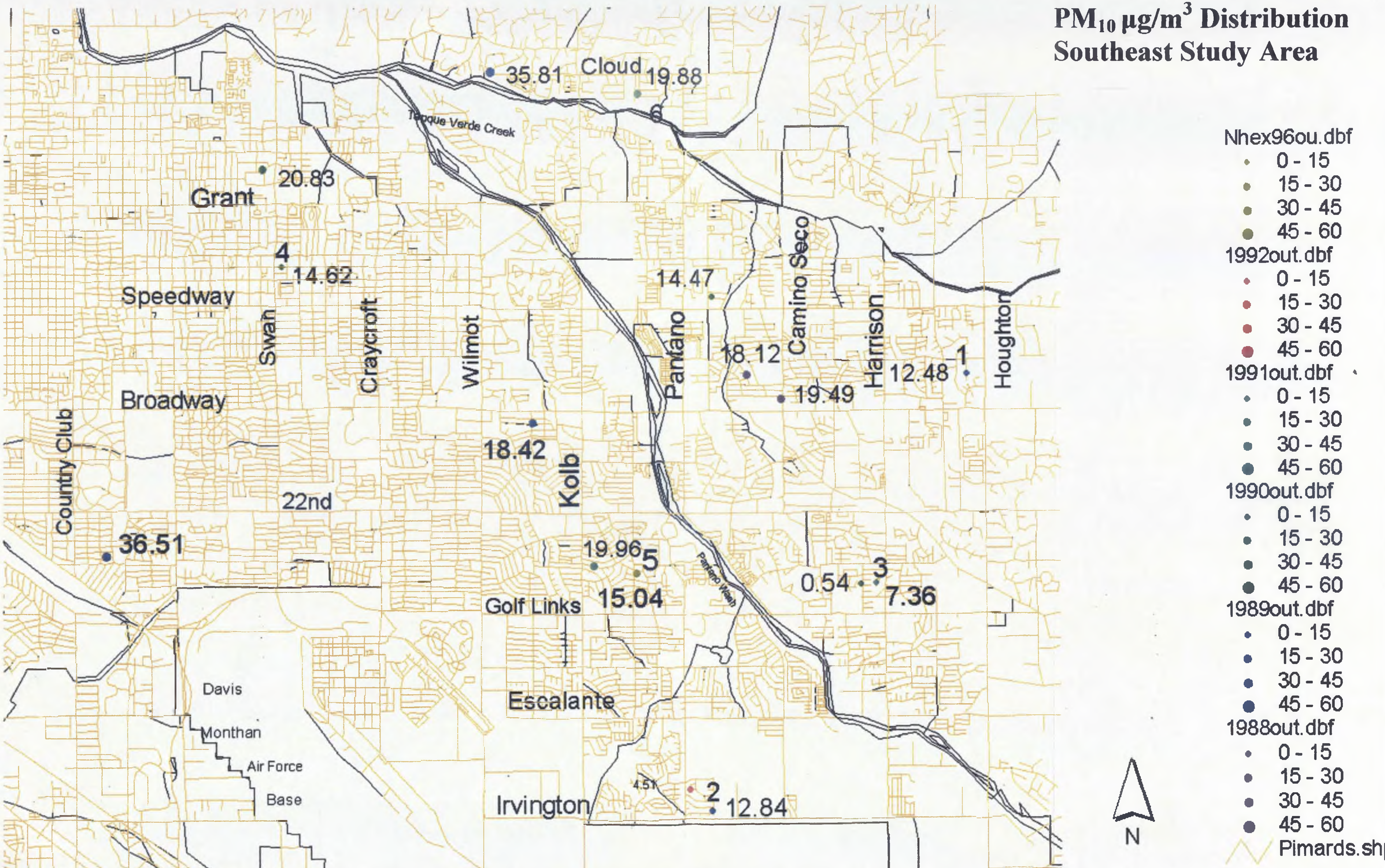
Distribution of sampling sites showing relative intensity of particulate matter (PM_{10} µg/m^3)
Coronado National Forest
I-10
I-10
I-19
Northwest study area
Southeast
Rillito Creek
Santa Cruz River
Canada Del Oro
Davis Monthan
Airforce Base
LEGEND
Nhex96ou.dbf
0 - 15
15 - 30
30 - 45
45 - 60
1992out.dbf
0 - 15
15 - 30
30 - 45
45 - 60
1991out.dbf
0 - 15
15 - 30
30 - 45
45 - 60
1990out.dbf
0 - 15
15 - 30
30 - 45
45 - 60
1989out.dbf
0 - 15
15 - 30
30 - 45
45 - 60
1988out.dbf
0 - 15
15 - 30
30 - 45
45 - 60
Pimards.shp
Tucson.shp
N

3. NORTHWEST STUDY AREA ($PM_{2.5}$ $\mu g/m^3$)

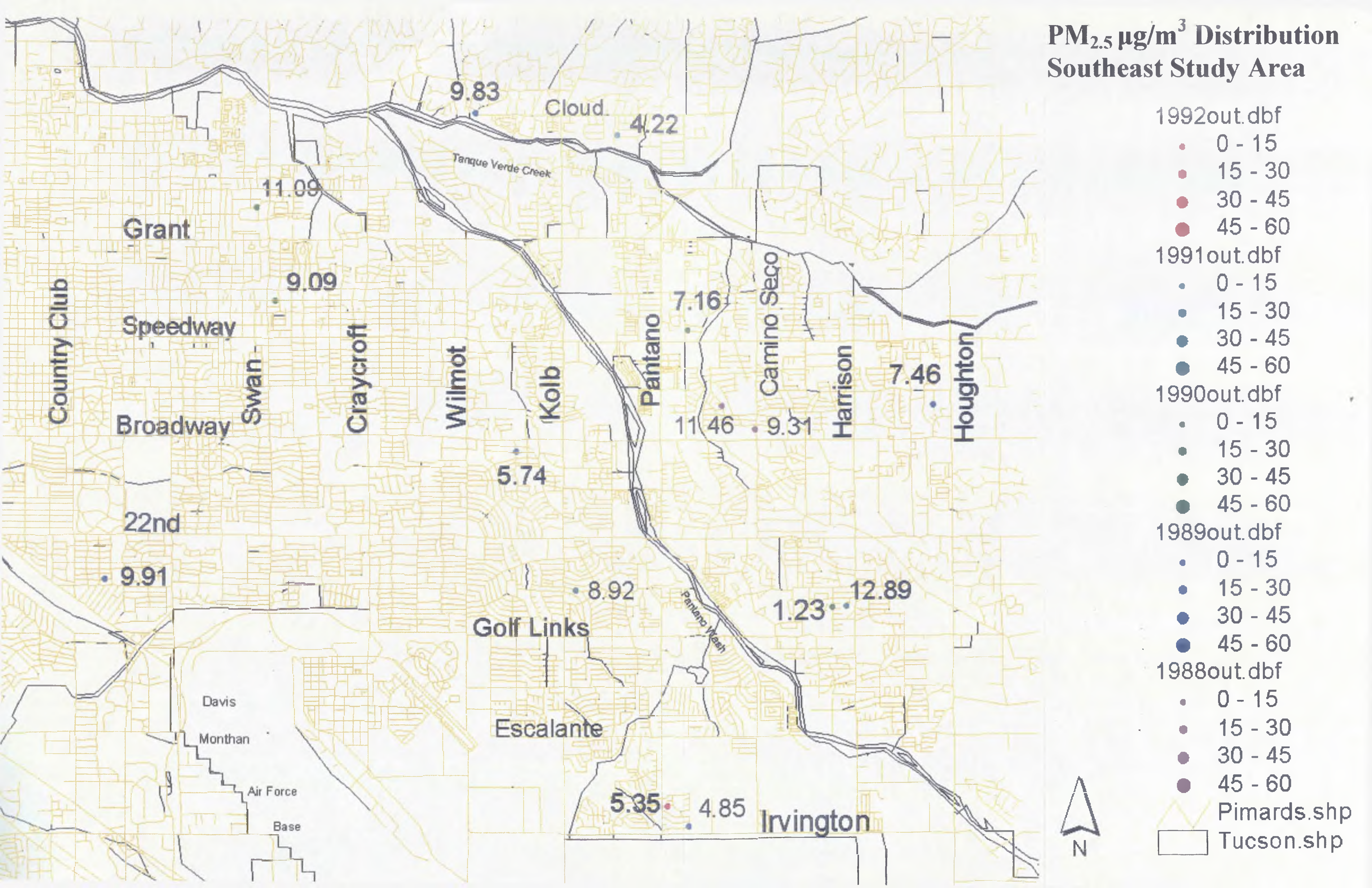


PM2.5 µg/m3 Distribution
Northwest Study Area
Ina
Canada Del Oro
Thornydale
6.51
Orange Grove
la Cholla
la Canada
Oracle
Pima Wash
1st
9.26
Sunset
9.79
4.07
Rillito Creek
I- 10
11.26
9.24
10.31
River
14.24
15.43
10.85
Wetmore
19.39
11.40
Prince
1992out.dbf
0 - 15
15 - 30
30 - 45
45 - 60
1991out.dbf
0 - 15
15 - 30
30 - 45
45 - 60
1990out.dbf
0 - 15
15 - 30
30 - 45
45 - 60
1989out.dbf
0 - 15
15 - 30
30 - 45
45 - 60
1988out.dbf
0 - 15
15 - 30
30 - 45
45 - 60
Pimards.shp
Tucson.shp
N

4. SOUTHEAST STUDY AREA (PM_{10} $\mu g/m^3$)


PM10 µg/m3 Distribution
Southeast Study Area
Cloud
35.81
19.88
6
Tanque Verde Creek
20.83
Grant
4
14.62
Speedway
Swan
Craycroft
Wilmot
14.47
Camino Seco
Harrison
Houghton
Pantano
18.12
19.49
12.48
1
Broadway
18.42
Kolb
Country Club
22nd
36.51
19.96
5
15.04
Golf Links
Pantano Wash
0.54
3
7.36
Davis
Monthan
Air Force
Base
Escalante
Irvington
4.51
2
12.84
N
Nhex96ou.dbf
0 - 15
15 - 30
30 - 45
45 - 60
1992out.dbf
0 - 15
15 - 30
30 - 45
45 - 60
1991out.dbf
0 - 15
15 - 30
30 - 45
45 - 60
1990out.dbf
0 - 15
15 - 30
30 - 45
45 - 60
1989out.dbf
0 - 15
15 - 30
30 - 45
45 - 60
1988out.dbf
0 - 15
15 - 30
30 - 45
45 - 60
Pimards.shp

5. SOUTHEAST STUDY AREA ($PM_{2.5}$ $\mu g/m^3$)


PM2.5 µg/m3 Distribution
Southeast Study Area
1992out.dbf
0 - 15
15 - 30
30 - 45
45 - 60
1991out.dbf
0 - 15
15 - 30
30 - 45
45 - 60
1990out.dbf
0 - 15
15 - 30
30 - 45
45 - 60
1989out.dbf
0 - 15
15 - 30
30 - 45
45 - 60
1988out.dbf
0 - 15
15 - 30
30 - 45
45 - 60
Pimards.shp
Tucson.shp
N
9.83
Cloud
4.22
Tanque Verde Creek
11.09
Grant
9.09
Speedway
Country Club
Swan
Craycroft
Wilmot
Kolb
Pantano
7.16
Camino Seco
Harrison
7.46
Houghton
Broadway
11.46
9.31
5.74
22nd
9.91
8.92
Pantano Wash
1.23
12.89
Golf Links
Davis
Monthan
Air Force
Base
Escalante
5.35
4.85
Irvington

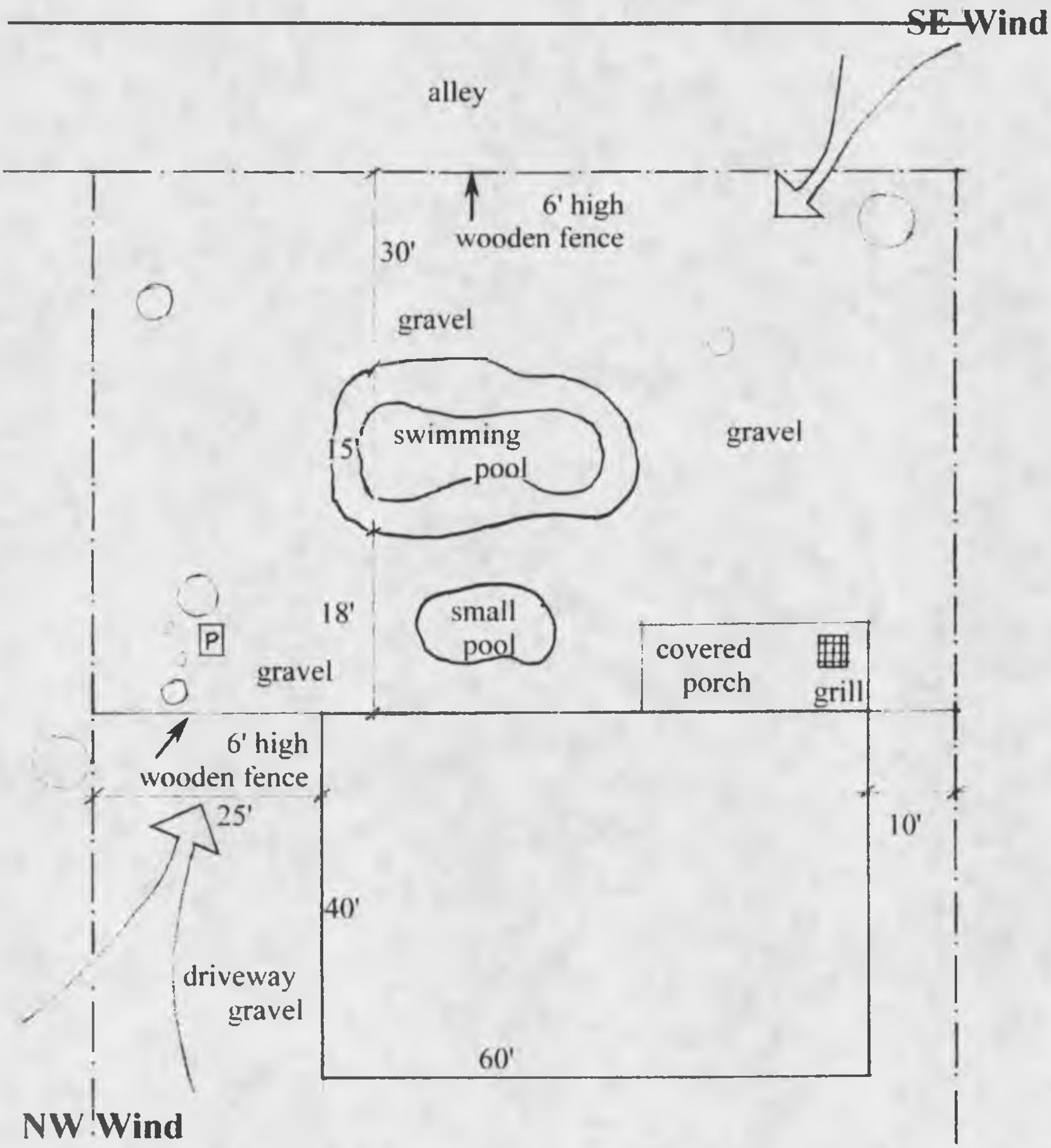
APPENDIX B : NORTHWEST STUDY AREA

B:1 : SITE 1

a. LAYOUT 1

b. PHOTOGRAPHS 1, 2, 3 AND 4

LAYOUT 1



P = PM box location

PHOTOGRAPH 1: Shows the northwest corner of the yard. The ground is covered with gravel.

PHOTOGRAPH 2: Shows the swimming pool with native vegetation in the backdrop.

PHOTOGRAPH 3: Shows the southeast corner, and the tall vegetation that is blocking the SE winds.

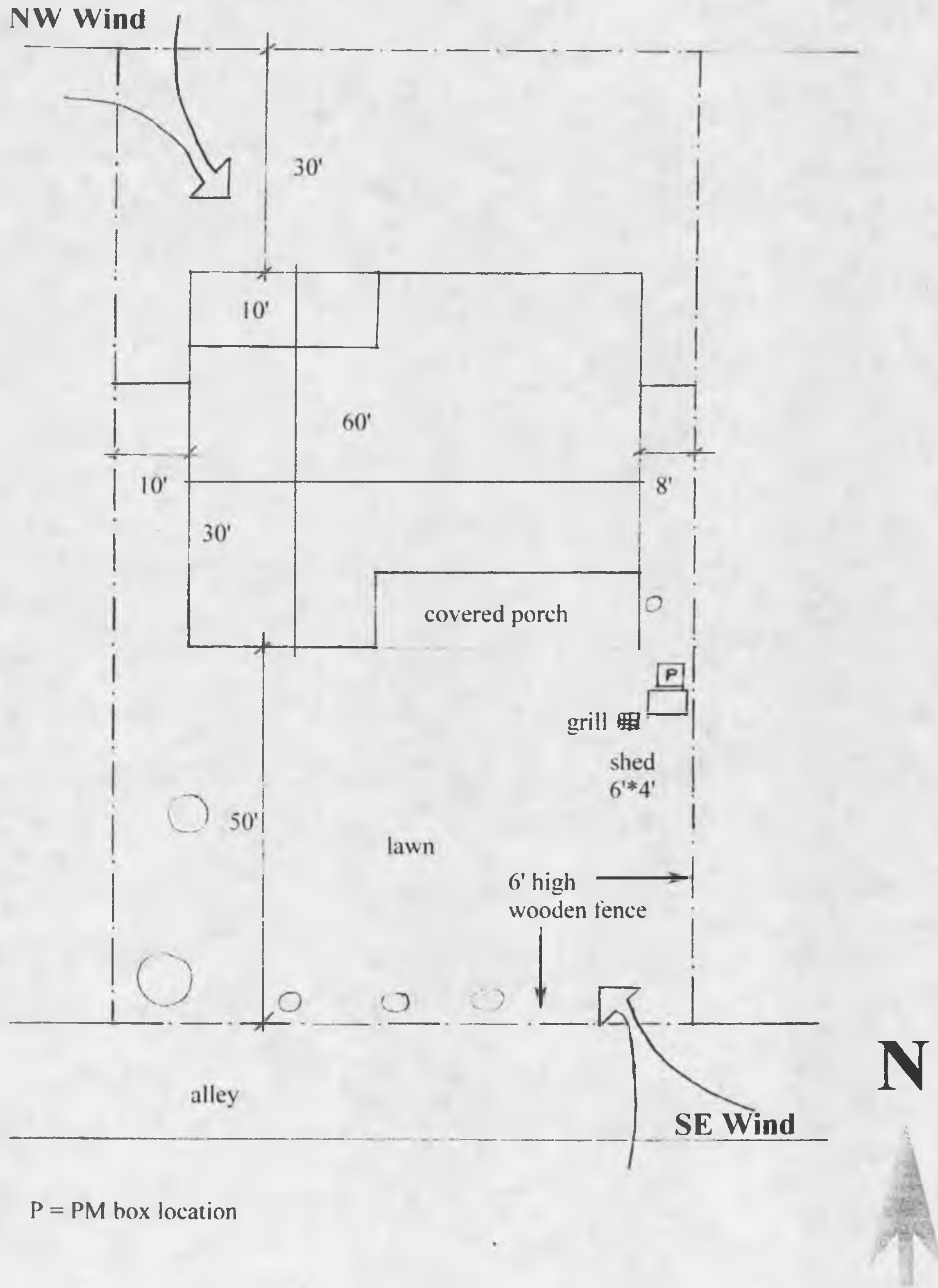
PHOTOGRAPH 4: Shows the gravel driveway that abuts the west fence of the yard.

B:2 : SITE 2

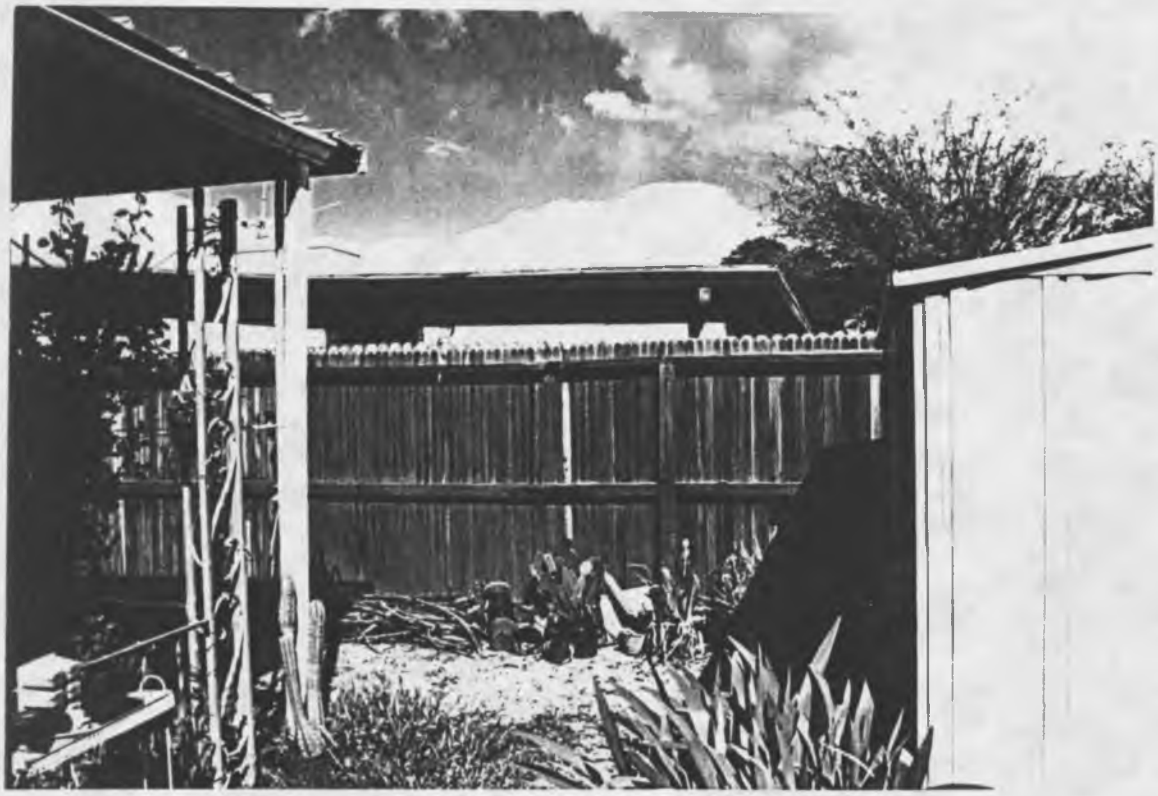
a. LAYOUT 2

b. PHOTOGRAPHS 5 AND 6

LAYOUT 2



P = PM box location



PHOTOGRAPH 5: Shows the eastern side of the yard that has exposed soil.

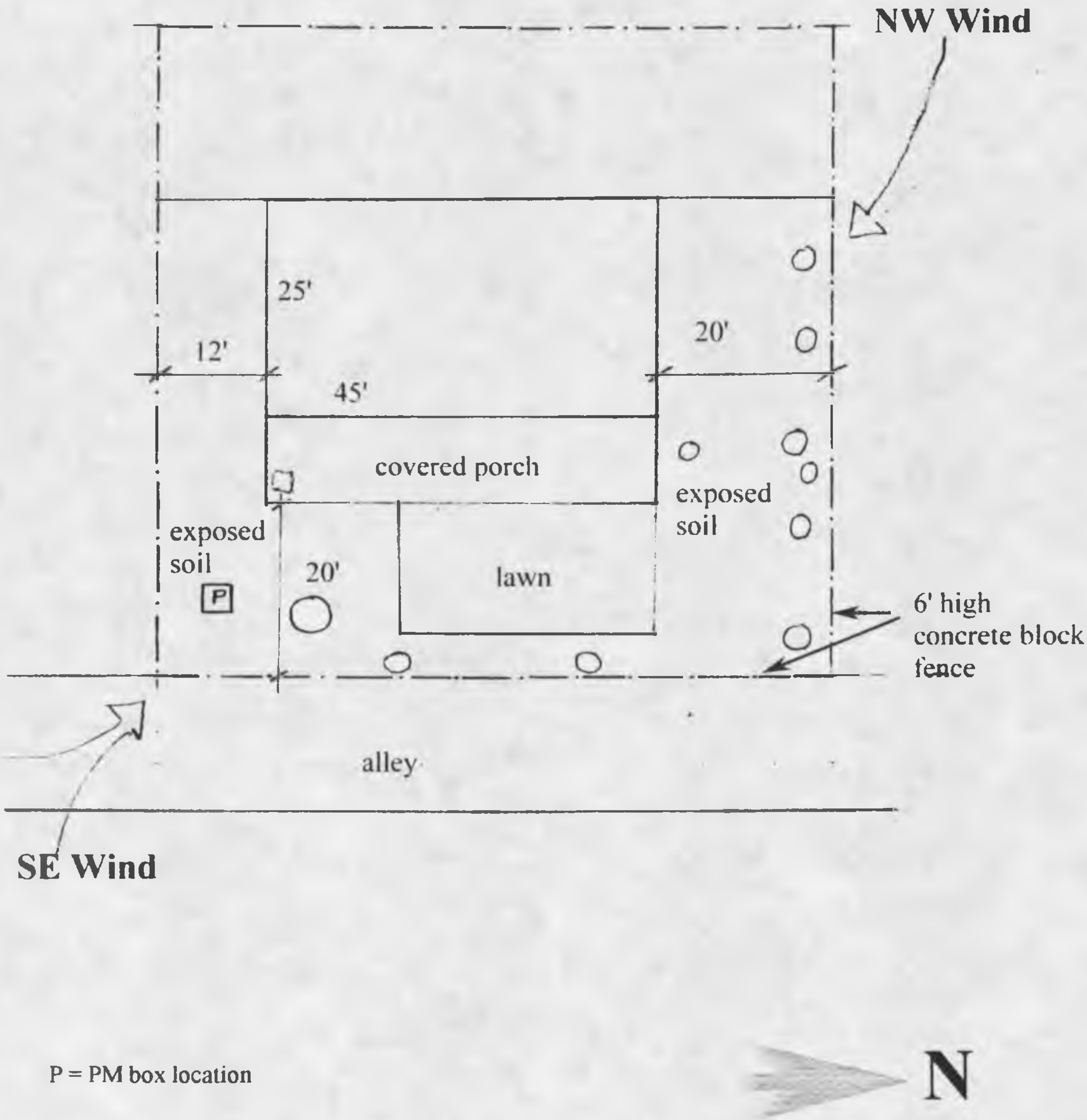
PHOTOGRAPH 6: Shows the SW part of the yard. Irrigated lawn covers most of the ground.

B: 3 : SITE 3

a. LAYOUT 3

b. PHOTOGRAPHS 7, 8, 9 AND 10

LAYOUT 3



P = PM box location

PHOTOGRAPH 7: Shows the SE corner of the yard where the PM sampler was kept.

PHOTOGRAPH 8: Shows the west side of the yard from under the porch.

PHOTOGRAPH 9: Shows the unpaved dirt alley that runs along the west wall of the yard.

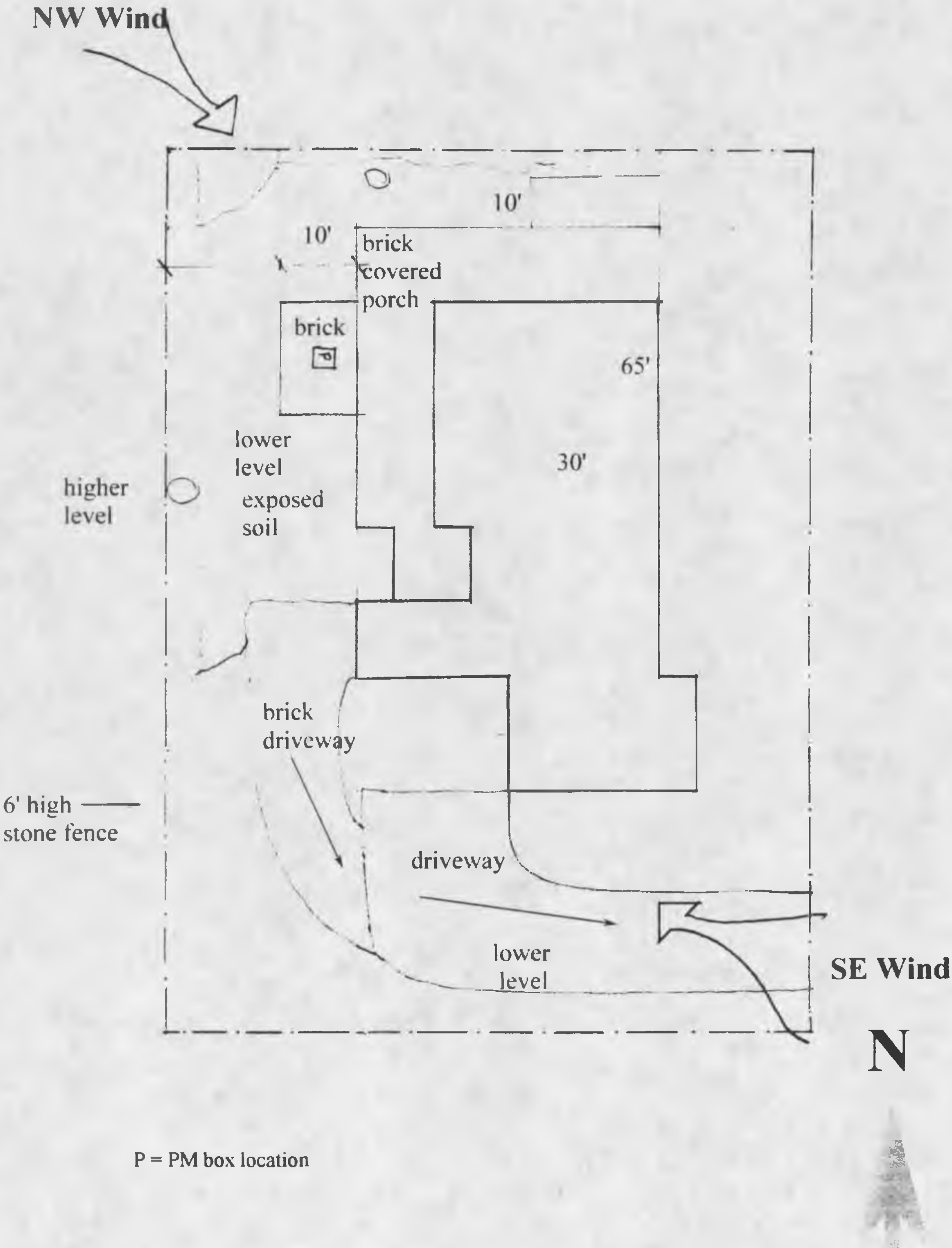
PHOTOGRAPH 10: shows the north part of the yard that has most of the vegetation.

B: 4 : SITE 4

a. **LAYOUT 4**

b. **PHOTOGRAPHS 11, 12 AND 13**

LAYOUT 4



P = PM box location

PHOTOGRAPH 11: Shows the driveway leading to the yard.

PHOTOGRAPH 12: Shows the north side of the yard. The PM box was placed on the brick paving.

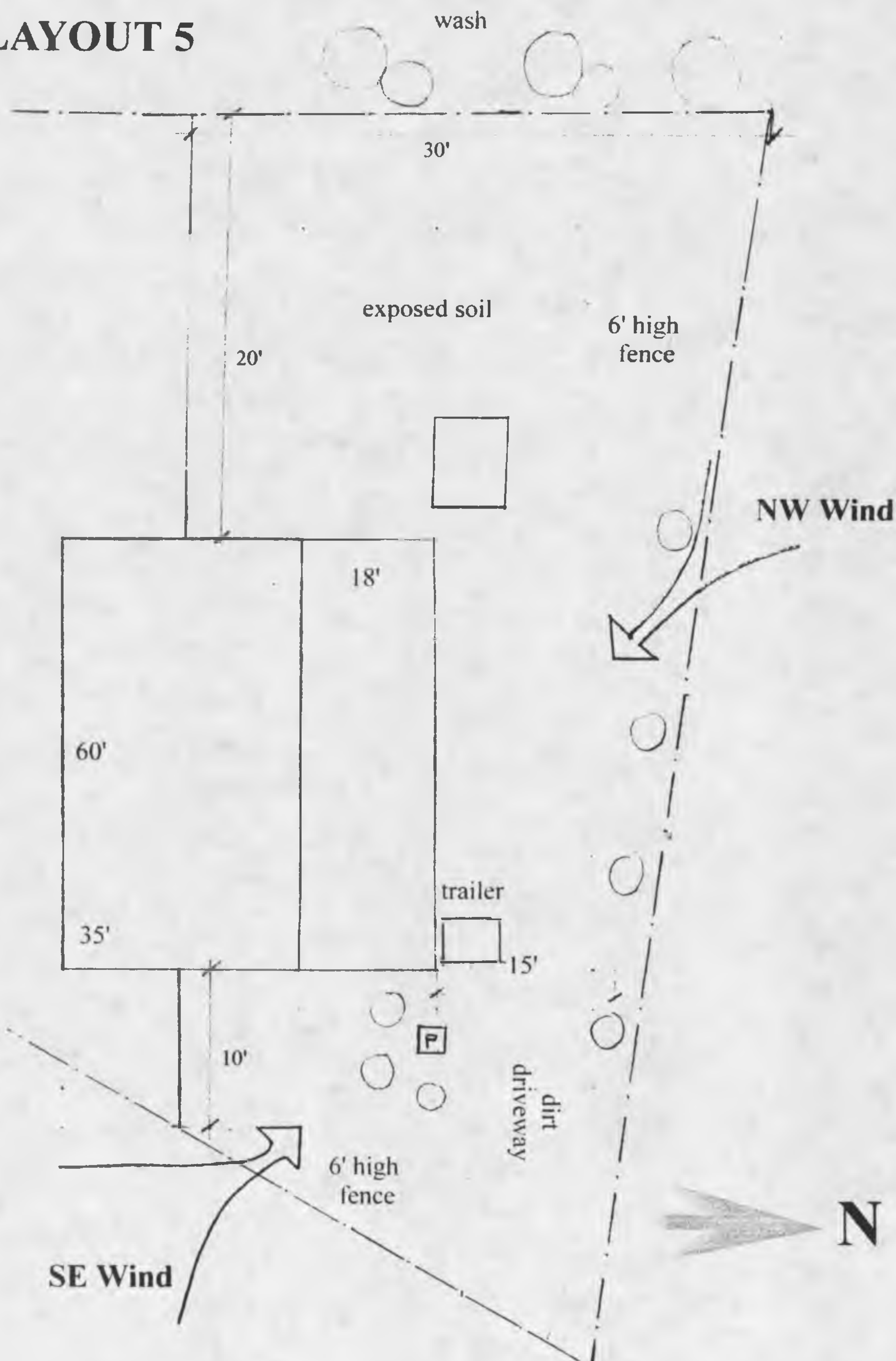
PHOTOGRAPH 13: Shows the east side of the yard.

B: 5 : SITE 5

a. LAYOUT 5

b. PHOTOGRAPHS 14, 15 AND 16

LAYOUT 5



P = PM box location

PHOTOGRAPH 14: The PM box was placed between the vegetaion and the dirt driveway.

PHOTOGRAPH 15: Shows the dirt driveway.

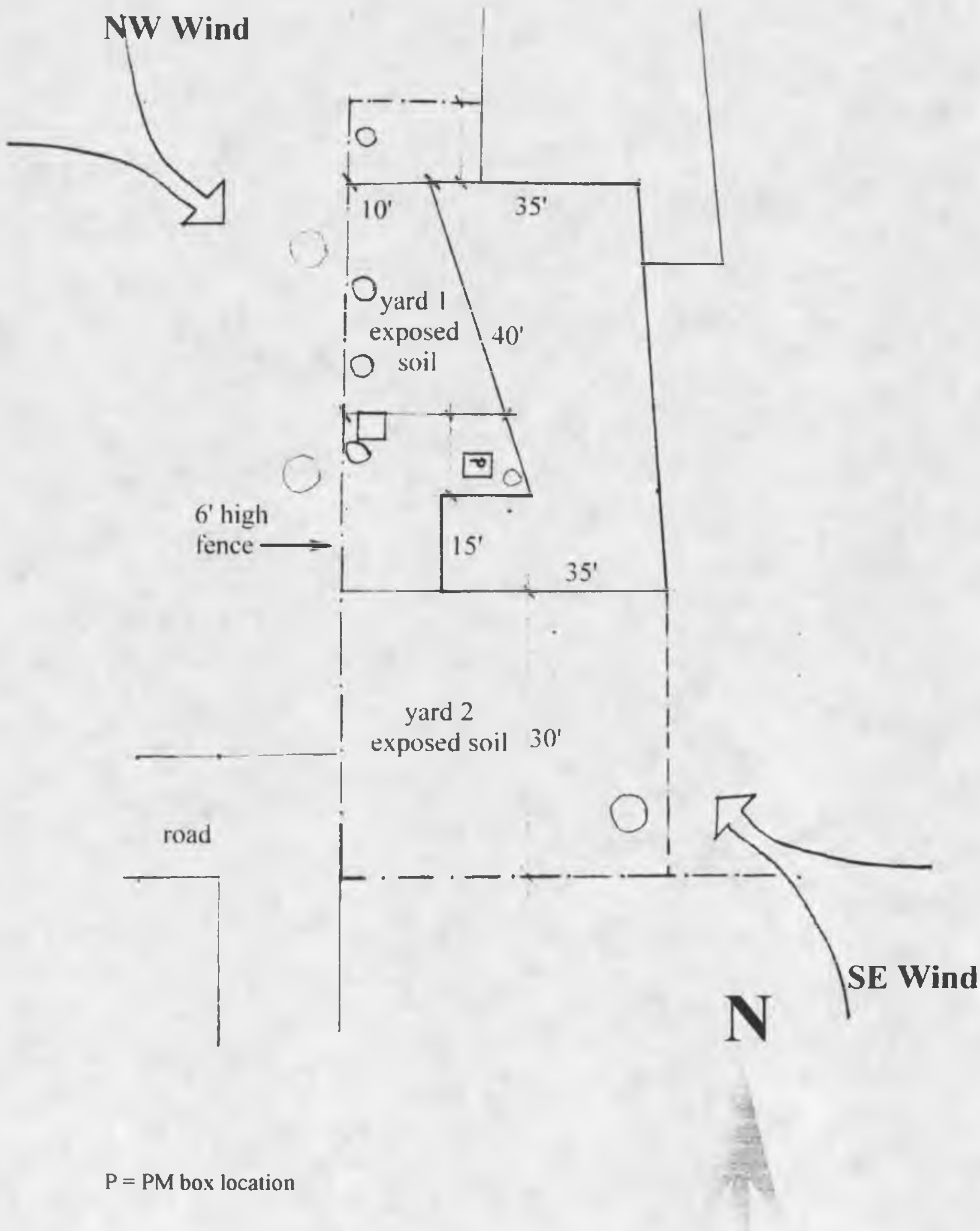
PHOTOGRAPH 16: Shows the north fence and the vegetation along the edge.

B: 6 : SITE 6

a. LAYOUT 6

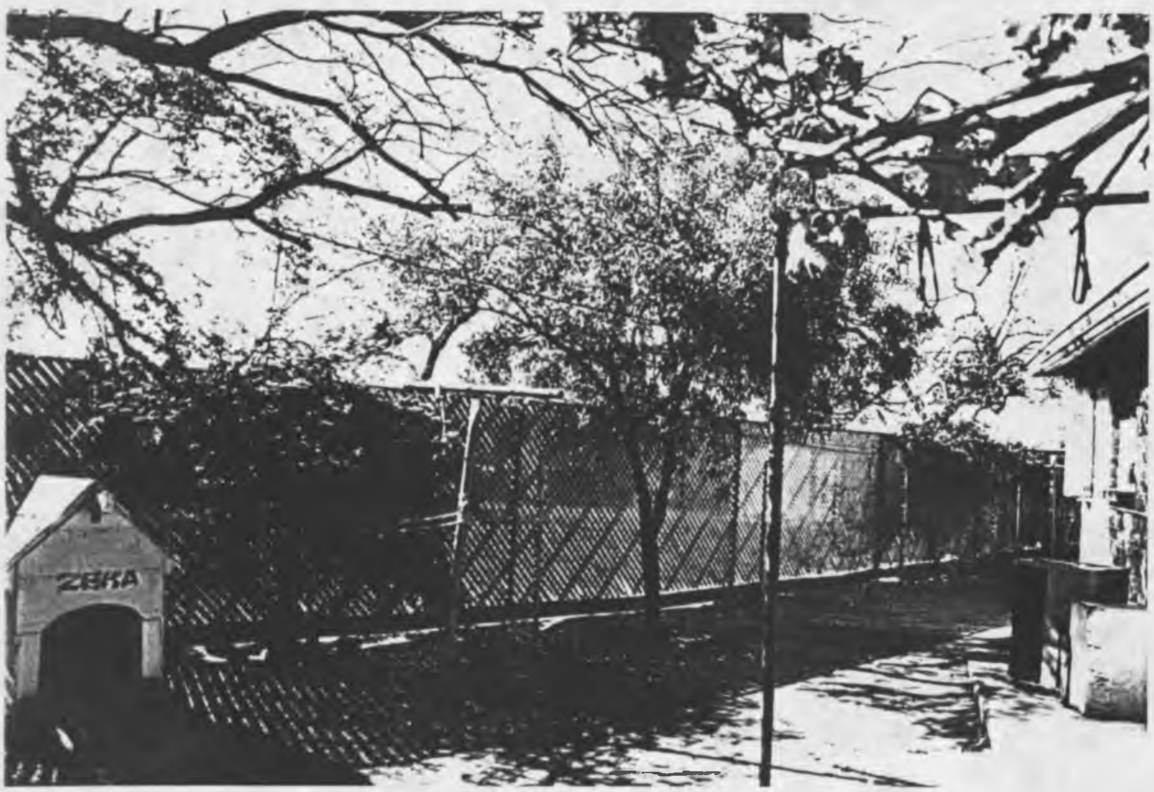
b. PHOTOGRAPHS 17 AND 18

LAYOUT 6



P = PM box location

PHOTOGRAPH 17: Shows that the whole yard has only exposed soil.



PHOTOGRAPH 18: Shows the north fence with very little vegetation along the edge.

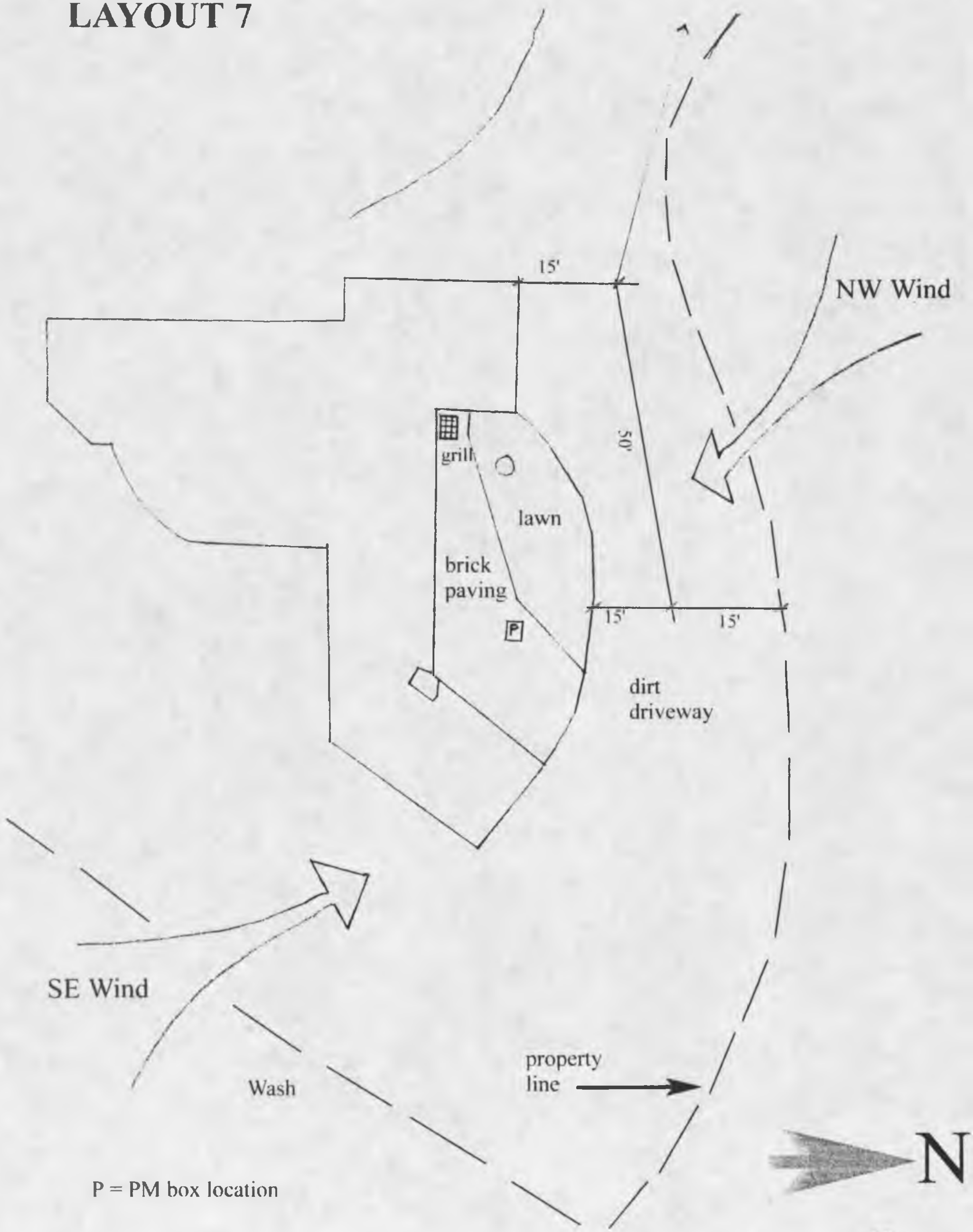
APPENDIX C : SOUTHEAST STUDY AREA

C: 1 : SITE 7

a. **LAYOUT 7**

b. **PHOTOGRAPHS 19 AND 20**

LAYOUT 7


15'
NW Wind
50'
grill
lawn
brick
paving
P
15'
15'
dirt
driveway
SE Wind
Wash
property
line
N
P = PM box location

PHOTOGRAPH 19: The yard is enclosed within a low brick fence. The lawn yard cover is also visible.

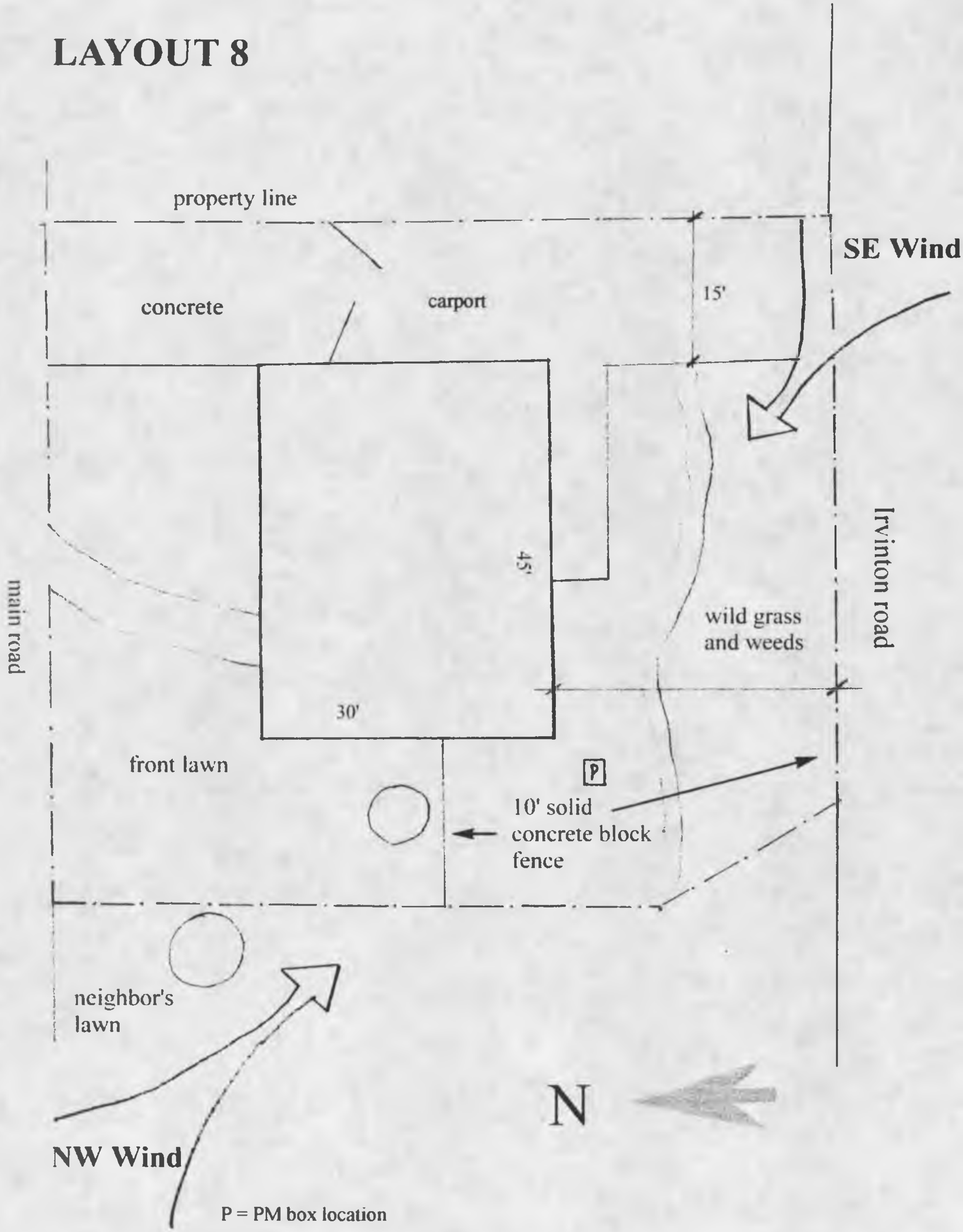
PHOTOGRAPH 20: The dirt driveway runs in front of the yard on the north side.

C:2 : SITE 8

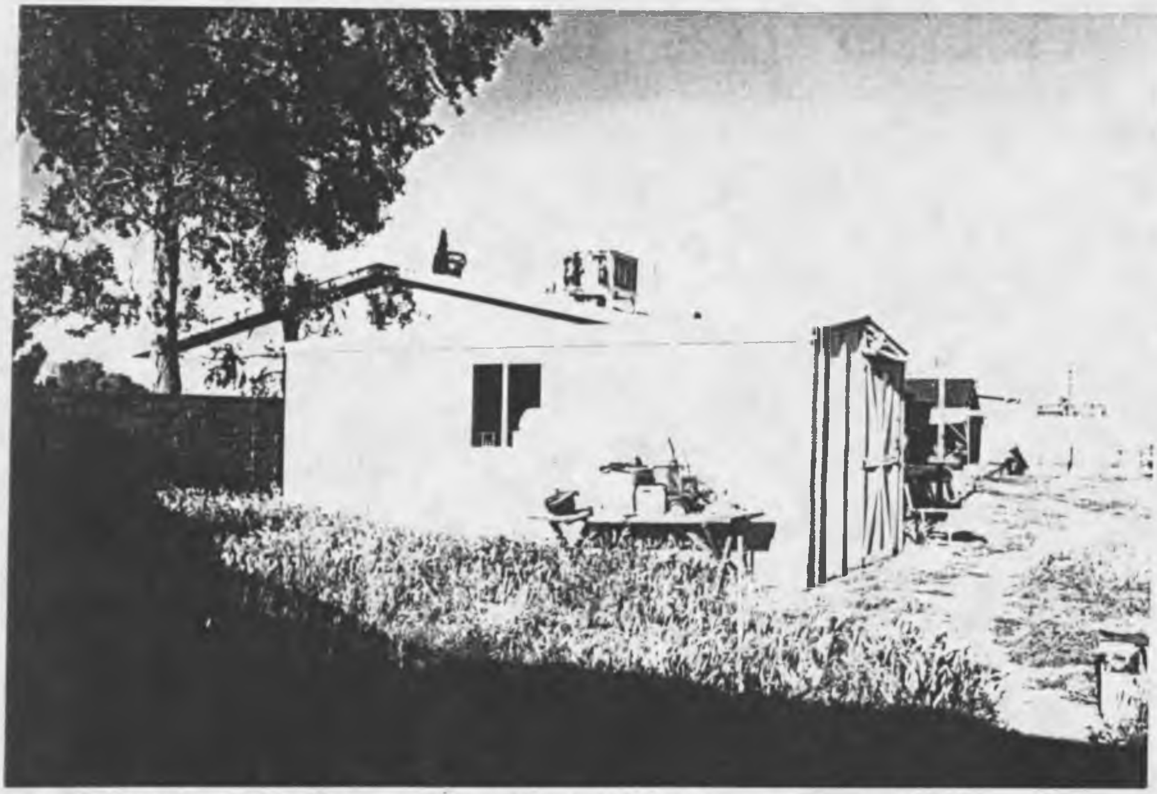
a. **LAYOUT 8**

b. **PHOTOGRAPHS 21 AND 22**

LAYOUT 8



P = PM box location



PHOTOGRAPH 21: The PM box was placed where the shed is seen right now in the photograph.

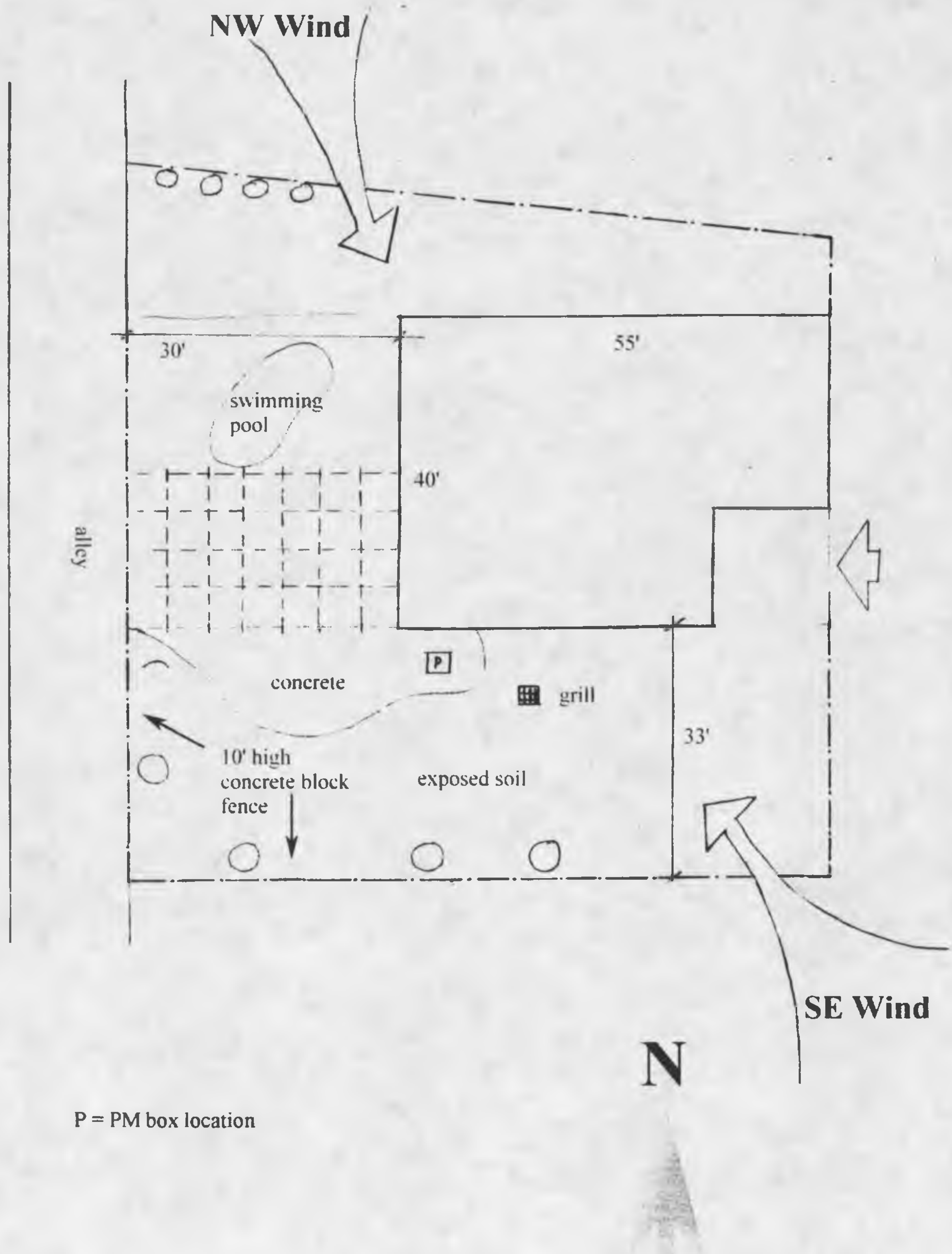
PHOTOGRAPH 22: This view is from the neighbor's house on the north side.

C: 3 : SITE 9

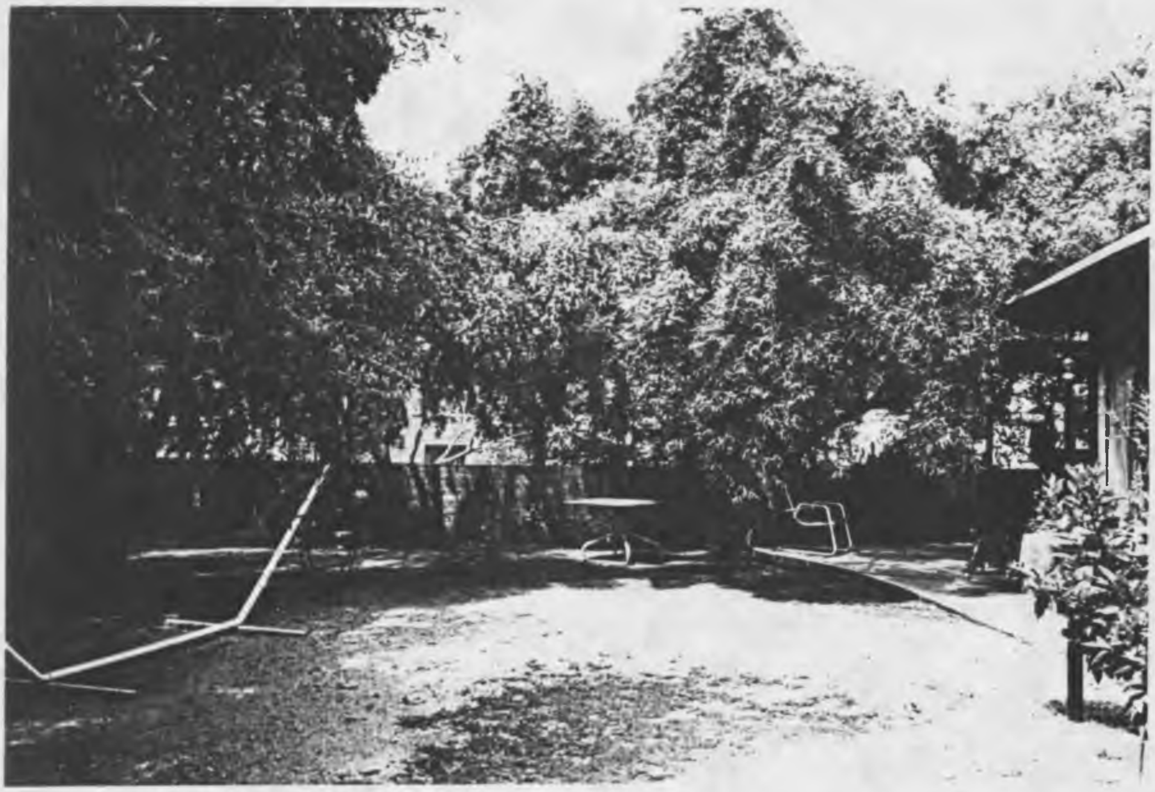
a. **LAYOUT 9**

b. **PHOTOGRAPH 23**

LAYOUT 9



P = PM box location



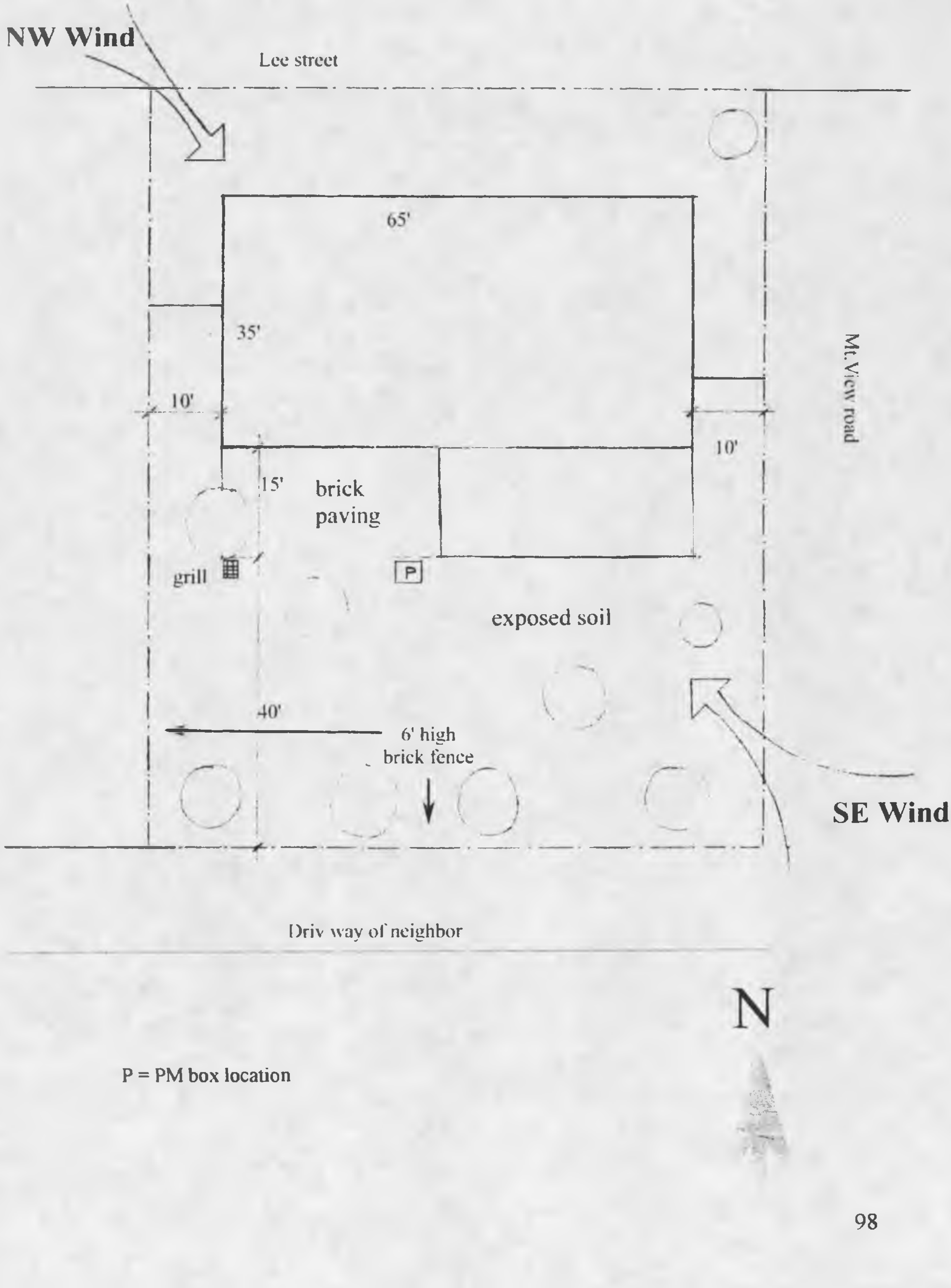
PHOTOGRAPH 23: This is taken from the SE corner of the yard facing the west fence. Most of the ground has exposed soil. The vegetation and alley runs along the west fence.

C: 4 : SITE 10

a. **LAYOUT 10**

b. **PFOTOGRAPHS 24, 25 AND 26**

LAYOUT 10



P = PM box location

PHOTOGRAPH 24: This view shows a part of the southeast corner, and the brick paving in front of which the PM box was placed.

PHOTOGRAPH 25: This photograph shows the northern part of the yard.

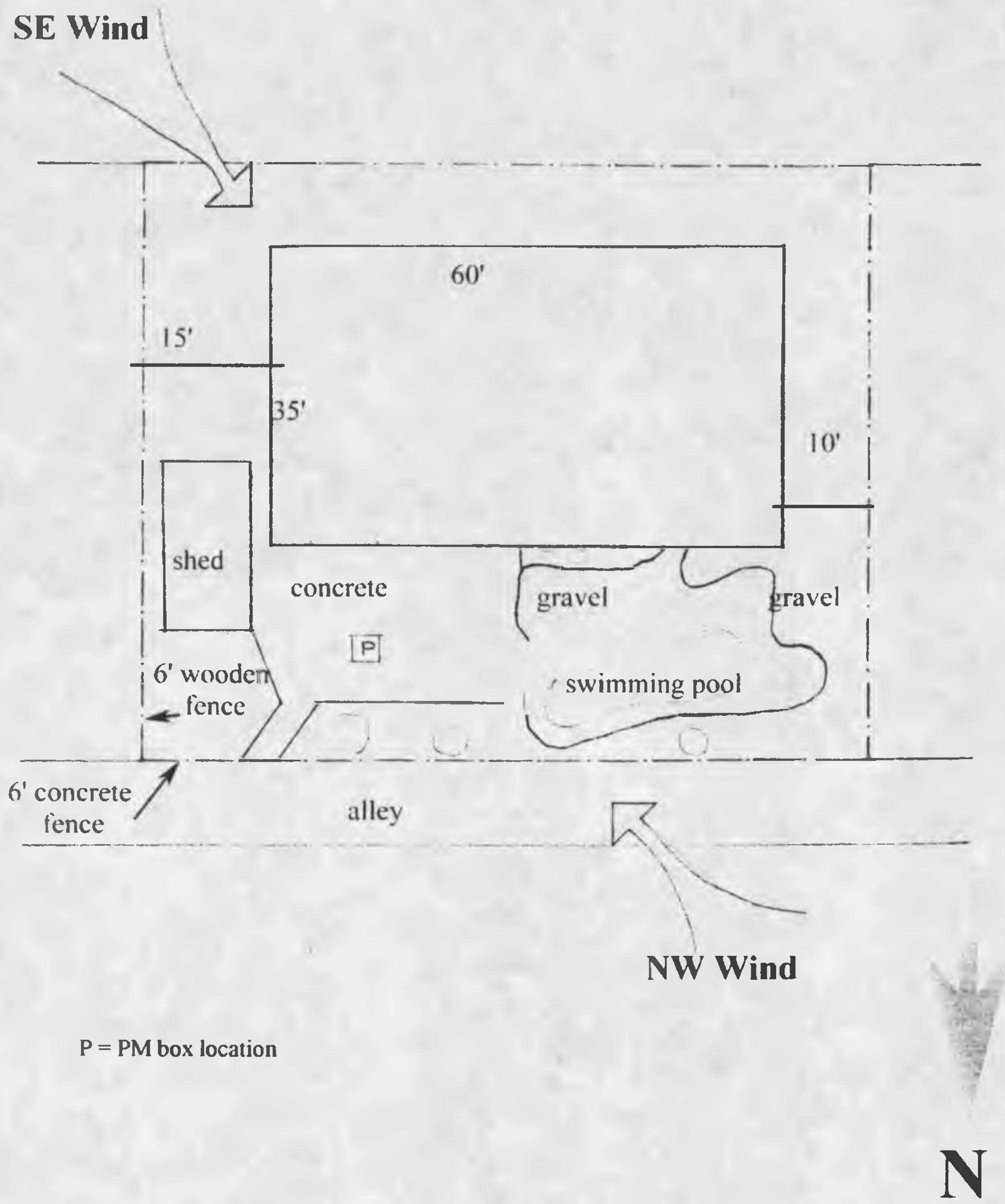
PHOTOGRAPH 26: This photograph shows the south side of the yard.

C: 5 : SITE 11

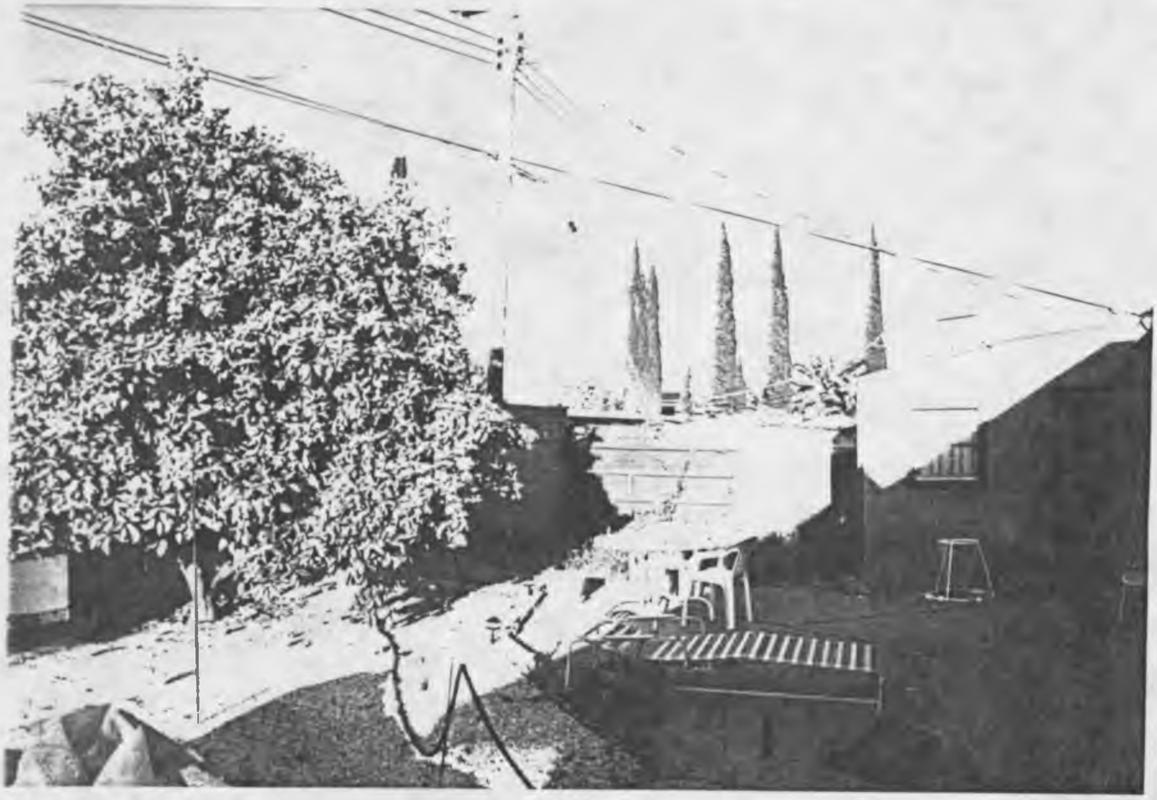
a. **LAYOUT 11**

b. **PHOTOGRAPHS 27 AND 28**

LAYOUT 11



P = PM box location



PHOTOGRAPH 27: Shows the east side of the yard. The PM box was placed on the concrete paving.

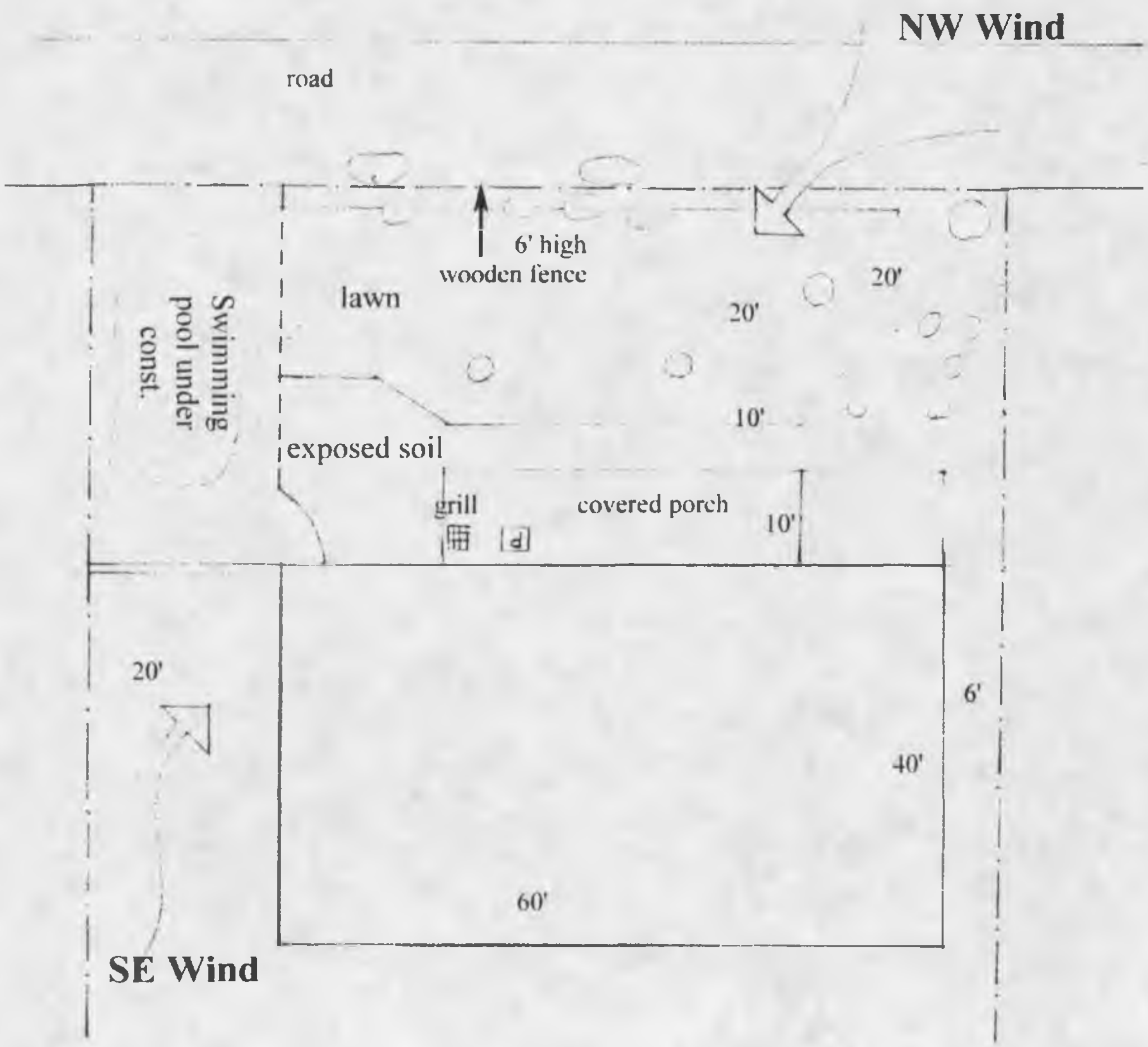
PHOTOGRAPH 28: Shows the NW corner with the swimming pool.

C: 6 : SITE 12

a. **LAYOUT 12**

b. **PHOTOGRAPHS 29, 30 AND 31**

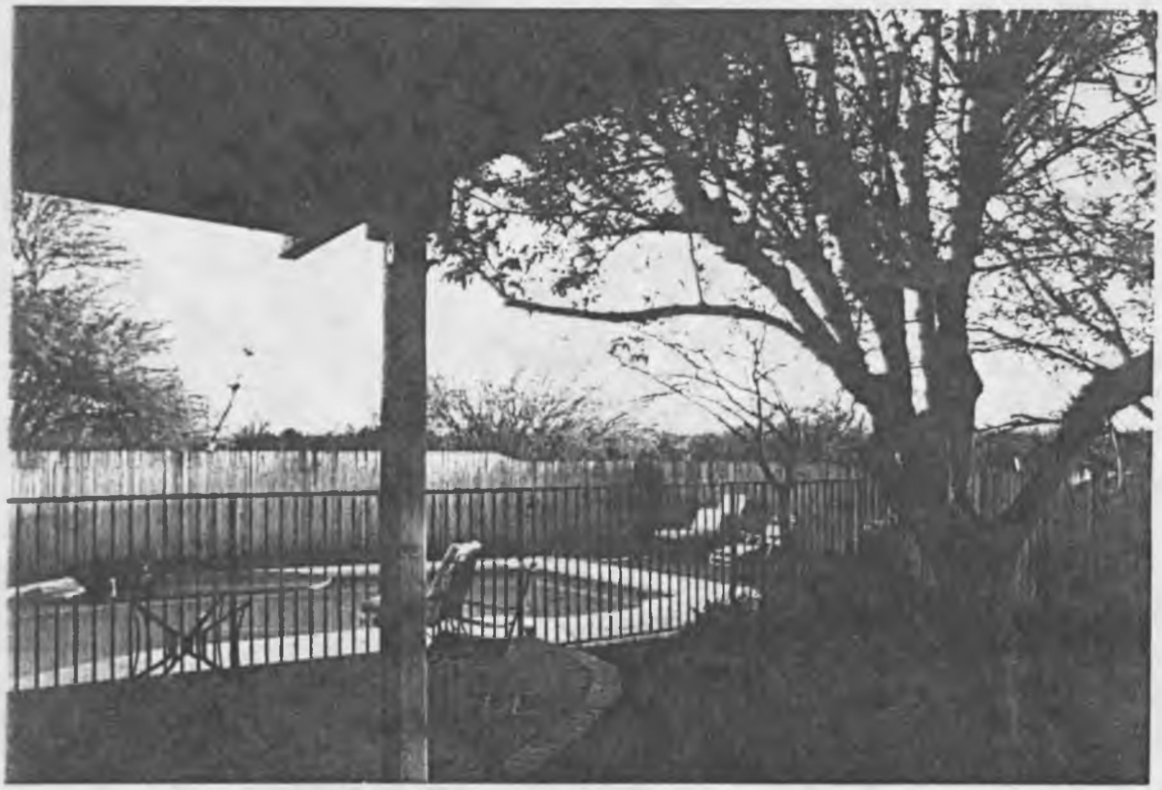
LAYOUT 12



P = PM box location

PHOTOGRAPH 29: shows the view of the porch under which the PM box was placed.

PHOTOGRAPH 30: Shows the NW part of the yard.



PHOTOGRAPH 31: This is a view of the swimming pool on the SW side. which was under construction at the time the PM sample was taken.

APPENDIX D: TABLES

TABLE 1: Data Summary - Northwest Study Area

Site location, house hold ID

Particulate matter data

Address	Pomona rd	Bromley st	Nova pl	Hill Crest dr.	Flint ave	Calle AZ
HHID	30914	30682	30106	30691	30550	30880
SITE #	**1**	**2**	**3**	**4**	**5**	**6**
PM_{10} ug/m^3outdoor	**14.18**	**14.24**	**17.78**	**23.28**	**23.47**	**38.03**
$PM_{2.5}$ ug/m^3 outdoor	.	**7.56**	**6.51**	**10.31**	**9.79**	**19.39**
Date Sampled	3/22/91	3/30/92	11/6/90	10/21/89	5/14/91	11/15/88
	4/8/91	4/6/92	11/13/90	10/27/89	5/21/91	11/21/88
PM Box Location	north,ne	south, se	east se	west, nw	north,nw	west

Yard cover

0= no cover
1= 0 -10%
2 = 10 - 25%
3 = 25 -50%
4 = 50 - 75%
5 = 75 - 100%

aggregate = gravel + concrete + brick + lawn/irrigated

Yard cover

exposed soil	1	2	4	4	4	5
gravel	4	1	0	0	0	0
concrete	1	1	1	0	0	1
brick	1	0	0	2	0	0
lawn/irrigated	0	3	1	0	1	0
others (wild grass, weed)	0	1	1	1	2	0
aggregate	5	4	2	2	1	1

Vegetation scale

no:of Trees, shrubs, plants

0 = no veg
1 = 1- 3
2 = 4- 7
3= 8 - 10
4 => 10

Vegetation type

trees	2	1	2	2	2	2
shrubs	4	4	2	4	4	2
other plants	3	2	0	2	1	0

Paving scale

paved / weeds =1
paved/ tar = 2
paved / brick =3
unpaved / gravel =4
unpaved/dirt/weed =5
unpaved /dirt/ veg = 6
unpaved / dirt =7

The aggregate of 7,6,5 are calculated in all the sites.

Paving

Alley	0	5	6	0	0	0
Driveway	4	0	0	3	7	7
road	2	0	0	0	4	2
throughfare	0	0	0	0	0	0
walkway /wash	0	0	0	0	6	0
Agrregate	0	5	6	0	7	7

Fence type scale

No fence = 0
house with fence <5' = 1
house with fence >5' = 2
chain link fence = 3
solid fence = 4
semi open = 5

Material code for:
fence, main building, porch area

no material = 0
concrete block = c
wood = w
vinyl, asbestos = va
brick = b
stone = s
plastic =p

Fence type	2,4,w	2,4,w	2,4,c	2,4,s	2,3,4,p	2,3,5,p
Build Mat	b	b	b	b	b	b va
Fence material	w	w	c	s	p	p
Porch area	0	va	0	c, w	0	0

Openness to WindFlow

0 = no flow
1 = low
2 = low - medium
3 = medium
4 = medium - high
5 = high

Openness to Wind Flow

Northwest wind	4	1	2	3	5	3
Southeast wind	4	3	1	1	4	1

No : Of Dogs

Dogs	1	1	1	1	3	2

Other Variables scale:

no =0
yes = 1

Other Variables

Barbeque grill	1	1	1	0	1	1
Fire place	0	1	1	1	1	1
Swimming Pool	1	0	0	0	0	0

Precipitation scale

Percentage of days rained = (No:of days rained / sampling period) *100

Precipitation

Percentage of days rained	43%	33%	0	29%	0	0
Total Rainfall (inches)	0.31	0.38	0	0.27	0	0

TABLE 2: Data Summary - Southeast Study Area

Site location, house hold ID

PM Concentration

Address	Scrader.ln	Manitoba	Deertail.cir	Lee.st	32nd st	Cam.suerto
HHID	34404	33552	32777	32633	516756	31062
SITE #	**7**	**8**	**9**	**10**	**11**	**12**
PM_{10} ug/m^3outdoor	**12.48**	**12.84**	**12.89**	**14.62**	**15.042**	**19.88**
$PM_{2.5}$ ug/m^3 outdoor	**7.46**	**4.85**	**7.36**	**9.09**	.	**4.22**
Date Sampled	10/4/89	1/20/89	6/12/91	9/20/90	3/11/96	4/11/91
	10/14/89	1/28/89	6/20/91	9/27/90	3/18/96	4/16/91
PM Box Location	north	South	South	South	north	West

Yard cover

0= no cover
1= 0 -10%
2 = 10 - 25%

3 = 25 -50%
4 = 50 - 75%
5 = 75 - 100%

aggregate = gravel + concrete + brick + lawn/irrigated

Yard cover

exposed soil	2	2	4	4	2	3
gravel	0	0	0	0	2	1
concrete	0	1	2	1	3	1
brick	2	0	0	1	0	0
lawn/irrigated	3	0	0	0	0	3
others (wild grass, weed)	1	4	1	1	1	0
aggregate	4	1	2	2	4	4

Vegetation scale
no:of Trees, shrubs, plants

0 = no veg
1 = 1- 3

2 = 4- 7
3= 8 - 10

4 => 10

Vegetation type

trees	1	1	4	4	1	4
shrubs	3	0	2	1	1	1
other plants	0	0	2	1	0	0

Paving scale

paved / weeds = 1
paved / tar = 2
paved / brick = 3
unpaved / gravel

unpaved /dirt / weeds = 5
unpaved / dirt / veg = 6
unpaved / dirt = 7

The aggregate of 7,6,5 are calculated in all the sites.

Paving

Alley	0	0	7	0	5	0
Driveway	7	0	0	7	0	0
road	0	0	0	2	0	2
thoroughfare	0	2	0	2	0	0
walkway / wash	0	0	0	0	0	7
Aggregate	7	0	7	7	5	7

Fence scale

No fence = 0
house with fence <5' = 1
house with fence >5' = 2
chain link fence = 3
solid fence = 4
semi open = 5

Material code for:
fence, main building, porch area

no material = 0
concrete block = c
wood =w
vinyl, asbestos = va
brick = b
stone = s
plastic =p

Fence Type	1,4,b	2,4,b	2,4,c	2,3,4,c	2,4,w,c	2,4,w
Build Mat	b	b	c	b	b	b
Fence material	b	b	c	0	w,c	w
other vertical material	0	0	0	va	va	va, w

Opennesss to wind flow

0 = no flow
1 = low
2 = low - medium
3 = medium
4 = medium - high
5 = high

Openness to Wind Flow

Northwest wind	3	2	1	1	4	1
Southeast wind	0	4	2	2	1	2

No : Of Dogs

Dogs	0	2	1	0	1	1

Other Variables scale:

no =0
yes = 1

Other Variables

Barbeque grill	1	1	1	1	1	1
Fire place	1	1	0	0	0	1
Swimming Pool	0	0	0	0	1	0

Precipitation scale

Percentage of days rained = (No:of days rained / sampling period) *100

Precipitation

Percentage of days rained	18%	55%	33%	38%	0	0
Total Rainfall (inches)	1.45	0.29	0.19	0.01	0	0