MOISTURE BALANCE IN VENTILATION AIR AT THE WIPP FACILITY

by

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ABSTRACT

This study quantified moisture evaporation, moisture condensation or moisture absorption (moisture balance) in the ventilation air at the Waste Isolation Pilot Plant (WIPP) in relation with four intake parameters: temperature, relative humidity, barometric pressure, and airflow rates. The Waste Isolation Pilot Plant has eight Mine Weather Stations (MWS) located on the surface and underground. Each station measures dry bulb temperature, relative humidity, and barometric pressure. In addition, there are fifteen airflow sensors located at strategic points in the underground facility. Currently this information is used for natural ventilation pressure calculations and mine ventilation simulations. For the purpose of this study, air properties at each MWS are computed from these data using psychrometric equations. Air properties computed are air moisture content, specific density, and specific volume. The amount of moisture flowing in the air is then computed using these air properties and measured airflow rates

Multiple linear regression analysis is used as the main tool for the development of the mathematical relationships that allow estimating moisture balance using real time data from the MWS. Data collected for a period of one year is used in the analysis at two hour sampling interval.

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Accomplishing my goals would not be possible without the moral support of my parents Eulogio and Segundina, and my brother and sisters Omar, Ivette and Sara who despite of the physical distance are always with me.

LIST OF ABBREVIATIONS AND NOTATIONS

AI : Air Intake shaft

BP : Barometric pressure, kPa

C_r : Specific heat of salt, J/kg

DV : Dependent Variables

e : Vapour partial pressure at air temperature, Pa

ES : Exhaust Shaft

e_{sd} : Saturation vapour pressure at air temperature, Pa

IV : Independent variables

k : Thermal conductivity of salt, W/m-K

M : Air mass flow rate, kg/s

M_{AI} : Air mass flow rate at AI shaft

M_{ES} : Air mass flow rate at the ES shaft

M_{SH} : Air mass flow rate at SH shaft

M_{UG} : Total air mass flow rate of AI and SH shafts

MWS : Mine Weather Station

P : Absolute pressure

P_{Hg} : Barometric pressure in inches of mercury, in Hg

P_{Pa} : Barometric pressure in Pascal, Pa

Q : Airflow rate, m^3/s

Q_E : Airflow rate in ft^3/s

R : Rate of evaporation/condensation, kg/s (l/s)

R^2 : Multiple determination coefficient (Correlation coefficient)

R_{AI} : Rate of condensation/evaporation at AI shaft

R_{ES} : Rate of condensation/evaporation at ES shaft

RH : Surface relative humidity, % / 100

RH_{ES} : Relative humidity at the base of the ES shaft

RH_{UG} : Weighted average relative humidity at the base of AI and SH shafts

RH_{WH} : Relative humidity at collar of the WH shaft

$R_{Meas.}$: Rate of condensation/evaporation calculated using actual or measured data

$R_{Mod\text{-}1}$: Model developed using all the 3334 points in the regression analysis

$R_{Mod\text{-}2}$: Model developed with additional data reduction

R_{SH} : Rate of condensation/evaporation at SH shaft

R_{UG} = Rate of condensation/evaporation at UG workings

SH : Salt Handling shaft

T : Surface temperature, °C (°F)

T_d : Dry bulb temperature, °C (°F)

T_{ES} : Temperature at the base of the ES shaft

T_K : Dry bulb temperature in Kelvin

T_{UG} : Weighted average temperature at the base of the AI and SH shafts, used as inlet conditions for UG workings area

T_w : Wet bulb temperature, °C (°F)

T_{WH} : Temperature at the collar of the WH shaft

UG : Underground Workings

V_{mapp} : Apparent specific volume based on 1-kg of dry air, m^3/kg

WH : Waste Handling shaft

X : Specific humidity / mass of water vapour, kg/kg (dry air) (g/kg)

X_1 : Specific humidity at point 1

X_2 : Specific humidity at point 2

α_r : Thermal difusivity, m^2/s

ρ : Density, gr/cm^3

ρ_m : Actual density of humid air at the location where Q was measured, kg (humid air)/m^3

Chapter 1

INTRODUCTION

1.2 Objective

In order to fulfill safety and health regulations, an underground facility must be properly ventilated. At the Waste Isolation Pilot Plant facility, in addition to safety and health regulations, the ventilation system should also provide for the confinement, channeling and filtration of potential airborn radioactive material in case of an accidental release. These demands require large quantities of air for ventilation. Such an amount of air flowing through the shafts and drifts carries a considerable amount of moisture being evaporated from the walls or condensed on the walls of the underground openings. This last process might also be associated with some absorption, which may occur in freshly exposed salt rock.

The objective of this study is to quantify the processes of evaporation, condensation or absorption, and be able to predict them.

1.3 Approach

Eight Mine Weather Stations (MWS) were installed at different strategic points in the underground WIPP facility to collect psychrometric data to calculate natural ventilation pressure. These data consist of dry bulb temperature, relative humidity and barometric pressure. Combined with airflow measurements, they can also be used for psychrometric calculations that establish moisture balance between two points.

The study was divided into five areas of interest, which are described in detail in Chapter 3:

1. Air Intake Shaft (AI)
2. Salt Handling Shaft (SH)
3. Waste Handling Shaft (WH)
4. Underground Workings (UG)
5. Exhaust Shaft (ES)

Multiple regression, a multivariate general linear model, is used as a main tool for this study. Data analysis and development of the models was accomplished using MINITAB, statistical software developed by MINITAB Inc.

1.4 Contents

The contents of this thesis include the following points:

- Chapter 2 gives a general description of the Waste Isolation Pilot Plant (WIPP).
- Chapter 3 describes the WIPP ventilation system.

- Chapter 4 provides the data acquisition procedure.

- Chapters 5 though 7 contain a summary of the literature review on salt rock properties, psychrometric theory and multivariate statistics (linear regression analysis).

- Chapter 8 provides a brief information about analysis of error propagation involved in the measurements and calculations.

- Chapter 9 depicts the development of the regression equations.

- Chapter 10 outlines the findings of the moisture balance quantification and the results and support of the regression equations developed in chapter 8.

- Chapter 11 and 12 summarize the conclusions and the recommendations drawn from this study.

Chapter 2

BACKGROUND

The Waste Isolation Pilot Plant is one of several sites providing a research and development facility to prove the safe disposal of radioactive waste resulting from the defense activities and programs of the United States of America. The site is located in the remote Chihuahuan Desert of Southeastern New Mexico, approximately 42 kilometers east of Carlsbad, New Mexico (Figure 2.1).

Disposal Rooms were excavated 655-m underground in a salt-bedded deposit, which is part of the Salado Formation. According to Barrows and Fett (1985) the stratigraphic column for the are shows its relationship to the other formations of the Delaware Basin. Although the Salado consist mostly of halite, it is also interbedded with polyhalite, anhydrite, and clayey to silty clastics. At the depth of the WIPP underground facility, the Salado formation, which is approximately 70 m thick, is relatively homogeneous (Figure 2.2).

Comment [E.R.P1]: Barrows, L. , and J. Fett. 1985. A high precision gravity survey in the Delaware Basin of southeastern New Mexico. Geophysics, vol. 50, no. 5, p. 825-833.

The underground workings consist of numerous interconnected drifts excavated in salt rock, in the same geological horizon and on a single level. Cartridges containing the waste material will be sealed in chambers excavated into the sides (ribs) of the drifts in the storage section of the mine (disposal rooms).

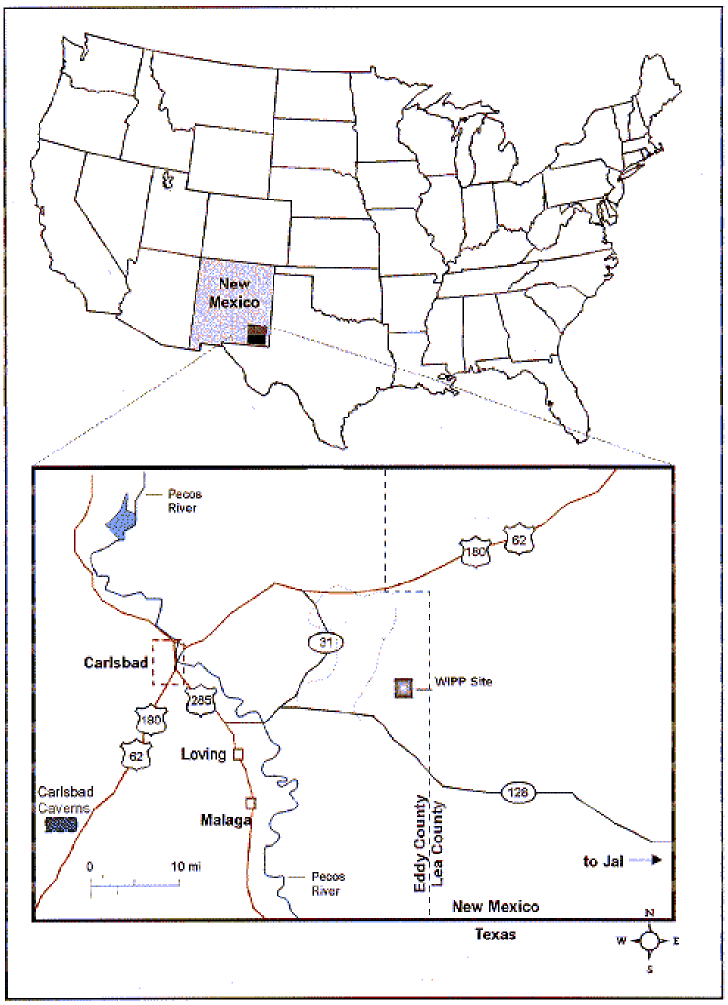

Figure 2.1 Location of the WIPP site (Obtained from the WIPP web-site)

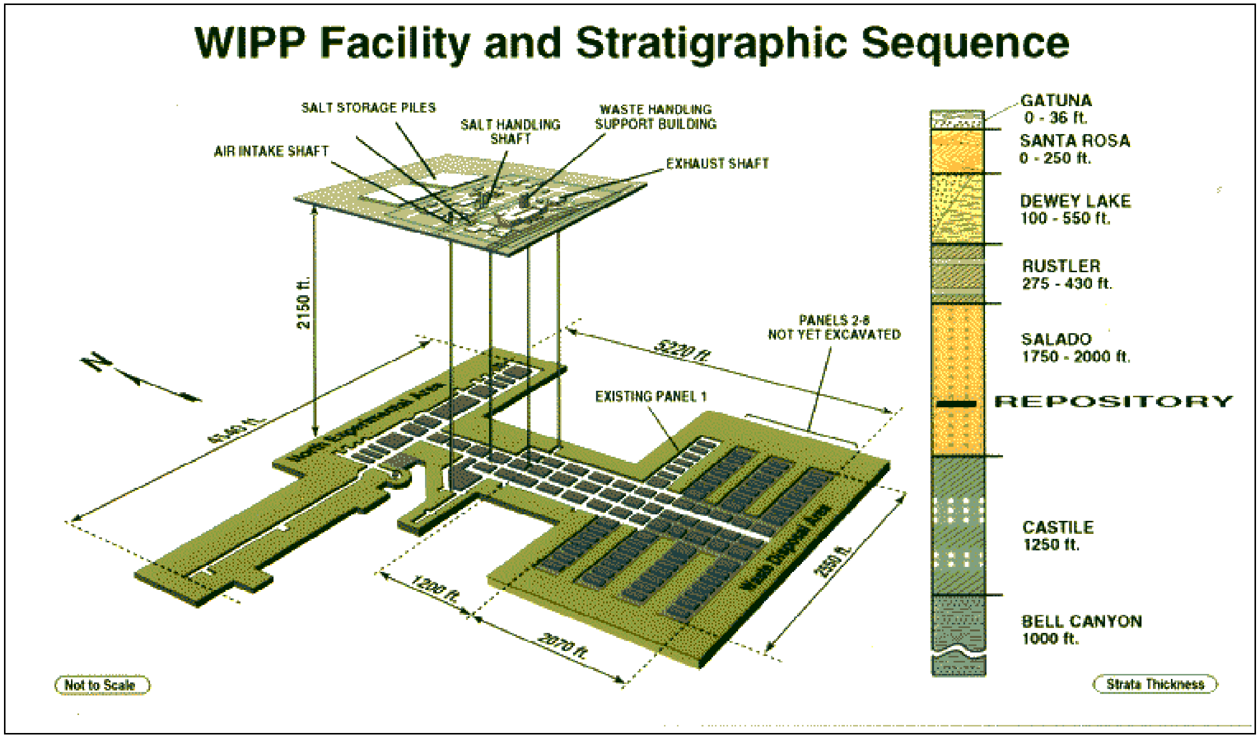

Figure 2.2 Disposal rooms excavated in the Salado Formation, about 70 m thick.
(Obtained from the WIPP web-site)

Chapter 3

WIPP VENTILATION SYSTEM

3.1 Functionality

The underground ventilation system at the WIPP site is designed to perform three main functions:

- Provide an appropriate working environment for underground personnel, and equipment during normal operations.

- Provide for the confinement, channeling and filtration of potential airborn radioactive material in case of an accidental release. For this purpose, the system is configured with a High Efficiency Particulate Air (HEPA) Filtration System.

- Provide for the confinement and reversal of the underground airflow in case of fire, using shaft isolation doors and underground booster fans.

3.2 Configuration

As shown in Figure 2.2 the underground ventilation system at the WIPP site consists of three vertical intake shafts (air intake shaft, salt handling shaft, waste handling shaft). In addition, it also consists of interconnecting drifts and crosscuts (underground workings) that are separated by bulkheads, air locks, and salt pillars. The entire system is connected to a common exhaust airway, (exhaust shaft), which connects to the main surface fans.

3.2.1 Air Intake (AI) shaft

The AI shaft (see Figure 3.1) is the primary supply of fresh air to the underground facility. It also provides emergency backup for transportation of personnel from the surface to the underground workings and vice versa. The AI shaft has a minimum of 4.87 m in diameter on the unlined sections. The nominal diameter of this shaft is 6.10 m.

3.2.2 Salt Handling (SH) shaft

The SH shaft is the secondary supply of fresh air to the underground areas. It is primarily used for transportation of salt to the surface, non-radioactive materials, and personnel. This shaft also provides routing for power, controls, and communication lines between surface and the underground facility. The SH shaft is the smallest in diameter of the four shafts, with a minimum diameter of 3.05 m in the smallest cross-sectional area, with a nominal 3.60 m in diameter.

3.2.3 Waste Handling (WH) shaft

The WH shaft is the primary fresh-air supply to the waste station area. To minimize the risk of contamination from the waste handling building this shaft supplies fresh air to the

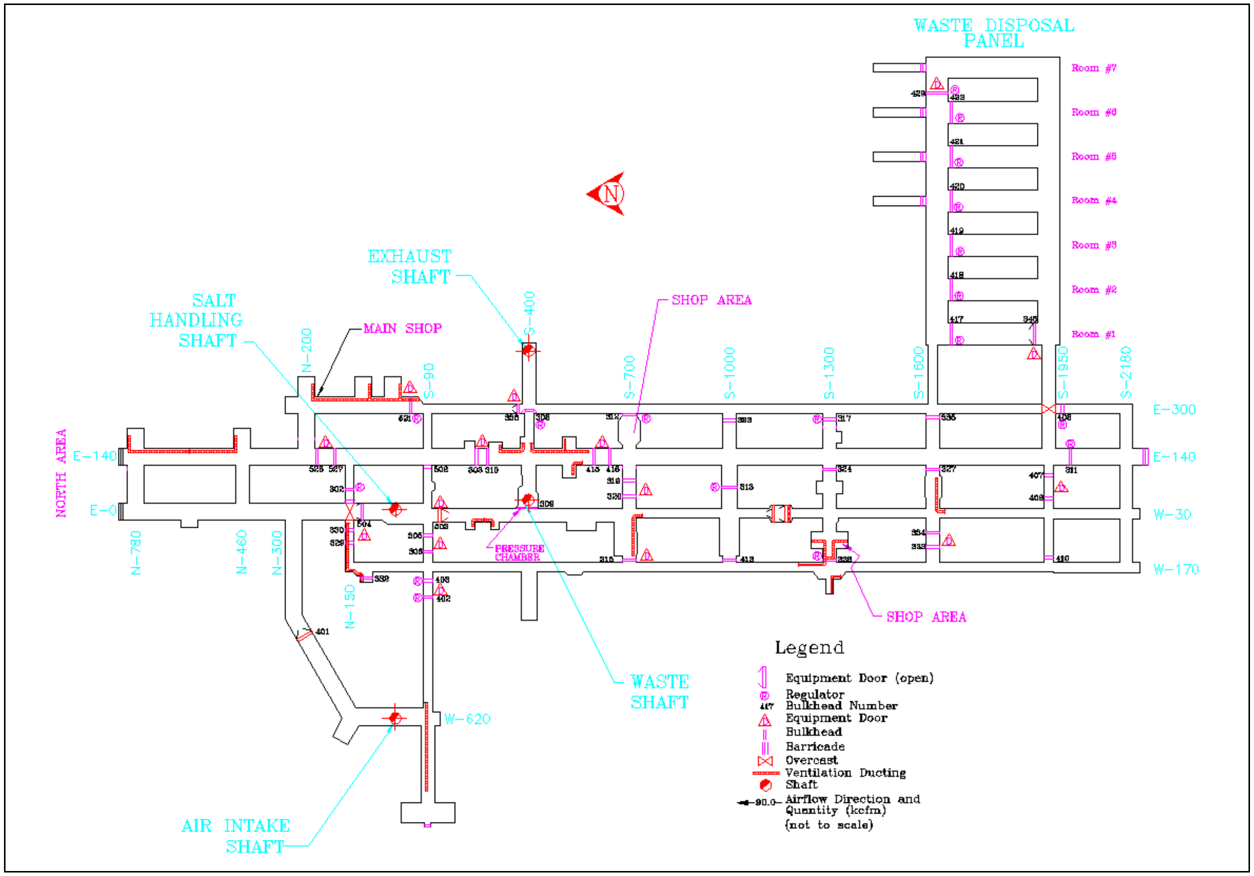

Figure 3.1 Underground facility infrastructure including shop locations, bulkhead numbers, door and regulator locations, and main shafts

station located at the base of the shaft only. From this point, the air is routed directly to the exhaust shaft. The shaft provides transportation for radioactive waste, underground mining equipment, materials, and personnel. The smallest section of the shaft is 5.80 m in diameter with a nominal of 6.10 m

3.2.4 Underground (UG) workings

The underground workings include all the drifts and crosscuts along the entire WIPP underground facility. It starts at the base of the AI and SH shafts and is treated as a sequence of serial connected airways throughout the entire facility, which ends at the base of the ES shaft. The WH shaft is not included since the air going through this shaft is directly sent to the ES shaft. Dimensions of the UG openings range from 5.2 m width by 4.3 m height, to 10 x 4.0 m width and height respectively.

3.2.5 Exhaust (ES) shaft

The ES shaft entirely used for exhausting the air from the underground workings. This shaft has a diameter of 4.27 m in the smallest cross-section with a nominal 4.57-m diameter.

Figure 3.1 shows the location of the different areas and the location of the shafts in a plan view of the underground facility.

3.3 Equipment

The ventilation system equipment can be classified into two groups: main fans, and auxiliary equipment.

3.3.1 Main fans

There are six ventilation fans, which supply airflow to the underground facility. They are located on the surface and at the top of the ES shaft. Three of these fans are the Main Fans (700A, 700B, and 700C), and three are the Filtration Fans (860A, 860B, and 860C). These fans are operated in various configurations (modes of operation) to provide the necessary airflow. The normal modes of are:

1. Normal Ventilation Mode: Two main 700-exhaust fans operating provide 230-m^3/s of air.

2. Alternative Ventilation: One main 700-exhaust fan operating provides 140-m^3/s of air.

3. Maintenance Ventilation: One main 700-exhaust fan and one or two 860 filtration fan operating provide approximately 140-m^3/s of air.

4. Reduced Ventilation: Two 860-filtration fans operating as ventilation fans provide 28-m^3/s of air.

5. Minimum Ventilation: One 860-filtration fan operating as a ventilation fan provides 28-m^3/s of air.

In addition to the normal modes of operation, the system has two different modes for off-normal conditions, such as radioactive release or an underground fire. They are:

1. Filtration mode: One 860-filtration fan operating with the HEPA filtration system providing 28-m^3/s of air.

2. Reversal mode: All the surface fans are deactivated and isolated using their dampers. The reversal is accomplished with the use of the underground booster fans.

Table 6.1 summarizes the characteristics of the main fans as well as the auxiliary fans located at the surface and underground facility.

Table 3.1 Fan specifications (MVS, 1999)

Comment [E.R.P2]: Waste Isolation Pilot Plant Mine Ventilation Plan May, 1999 MVS Inc. p 20

	MAIN VENTILATION FANS		**EBF FANS**	**BOOSTER FANS**
Equipment No	41-B-700A 41-B-700B	41-B-700C	41-B-860A 41-B-860B 41-B-860C	74-B-004A 74-B-004B 74-B-004B
Manufacturer	Chicago Blower	TLT Babcock	Novenco	Joy
Model	D/1910A	14144AC/1665/0 CW (Rbr =117)	BC/542	45-26-770CP
Type	Centrifugal	Centrifugal	Centrifugal	Axial
Size (Diam. m)	2.40	2.40	1.43	1.14
Speed (rpm)	710	710	1180	11770
Static Pressure (in. w.g.)	12.50	9.65	13.00	4.20
Air Quantity (m^3/s)	100	100	33	23
Efficiency (%)	N/A	TBD	83.3	76
Blade type	Airfoil	Airfoil	Airfoil	Airfoil
Motor HP	600	600	235	50
Voltage (V)	4160	4160	460	460

3.3.2 Auxiliary equipment

Each split to the four main areas of the underground facility is controlled by louver style regulators, which can be operated either remotely or manually. The regulators are mounted in four ventilation bulkheads. These bulkheads regulate airflow to the waste disposal area, mining area, north area, and the WH shaft station. In addition, there are also three booster fans located underground at each intake shaft. These booster fans operate in conjunction with the fire control doors and the booster fans to reverse the airflow at various parts of the facility in case of an underground or shaft fire.

Chapter 4

DATA ACQUISITION

The underground ventilation system at the WIPP facility is continuously monitored to ensure proper function. The monitoring system is capable of collecting data from airflow sensors and Mine Weather Stations located at strategic points and measuring air velocity, temperature, relative humidity and barometric pressure. This data is currently used for mine ventilation simulation and natural ventilation pressure calculations.

4.1 Underground ventilation remote monitoring

The underground ventilation remote monitoring and control system incorporates those elements necessary to monitor the underground airflow conditions and report those conditions to the Central Monitoring Station (CMS) (McDaniel & Wallace, 1997). These consist of air flow velocity sensing stations, differential static pressure sensing stations, and both control and monitor capability for air flow regulators located in bulkheads throughout the underground facility. The sensors send either a 0 to 5 V dc signal or a 4 to 20 mA signal to one of the four Local Processing Units (LPU) in the underground facility. The LPUs digitize and transform the signal into adequate units of air velocity (fpm or m/s), differential pressure (inches water gage, in. WG) and regulator position (% open). The analog signal is then transmitted to the surface Central Monitoring Room (CMR). At the CMR this real time information can be retrieved and displayed, in graphical or tabular form by interfacing to the

Comment [E.R.P3]: K.H. McDaniel and K.G. Wallace Jr. Real time mine ventilation simulation, Mining engineering August 1997, p 71-75

CMS though a computer program called the Plant Information (PI) Process Book. PI collects data, filters it and eventually stores the information permanently into the main operating system (VAX).

Airflow velocity is measured at fifteen stations underground. Data from seven of them, associated with the Mine Weather Stations are reported for this study. These stations, as well as their relative location are listed in table 4.1

Table 4.1 Airflow velocity stations as of June 1999

Weather station			Location (see Figure 3.1)
Number	Code	Units	
V1	AM1001	KCFM	In N215 at W500 (AI Shaft)
V2	AM1002	KCFM	In S400 at E250 (WH Shaft)
V5	AM1005	KCFM	In N150 at E15 (SH Shaft area)
V6	AM1006	KCFM	In E0 at N200 (SH Shaft area)
V7	AM1007	KCFM	In W30 at S800 (SH Shaft area)
V11	AM1011	KCFM	In W170 at S600
V15	AM1015	KCFM	In S400 at E400 (ES Shaft)

4.2 Temperature, relative humidity, and barometric pressure monitoring

Eight stations monitor air temperature, relative humidity and barometric pressure; four of them are located underground at the bottom of each shaft and four on the surface at the top of the SH, WH, and ES shafts. The station at the ES shaft monitors surface weather conditions. The eighth station is in the duct at the top of the ES shaft and measures air exhaust conditions. Table 4.2 summarizes the underground and surface weather stations included in the psychrometric calculations and analysis.

Table 4.2 Weather tations used in the psychrometric calculations

Weather station			**Location**
Number	**Code**	**Units**	
1	AP3152	DEG F	Base of the AI Shaft
	AP3153	PCT	
	AP3154	IN HG	
2	AP3155	DEG F	Base of the SH Shaft
	AP3156	PCT	
	AP3157	IN HG	
3	AP3158	DEG F	Base of the ES Shaft
	AP3159	PCT	
	AP3160	IN HG	
4	AP3161	DEG F	Base of the WS Shaft
	AP3162	PCT	
	AP3163	IN HG	
5	AP3164	DEG F	Collar of the SH Shaft
	AP3165	PCT	
	AP3166	IN HG	
6	AP3167	DEG F	Collar of the WH Shaft
	AP3168	PCT	
	AP3169	IN HG	
7	AP3170	DEG F	Collar of the ES Shaft (surface climatic conditions)
	AP3171	PCT	
	AP3172	IN HG	
8	AP3173	PCT	Surface ES Shaft Duct
	AP3174	DEG F	
	AP3175	IN HG	

The MWSs can collect temperature and relative humidity in the ranges of –35 to 50°C and 0 to 100% by a Visala HMP35C probe. Air Pressure is measured in the 800 to 1,060-mbar range by a Visala PTA 427 barometric pressure sensor. Relative humidity is always reported in percent moisture (%). These measurements are taken by the Campbell Scientific Inc. CR10 measurement and control system (McDaniel, 1998). This unit receives the analog signals from the sensors (temperature, barometri pressure, and relative humidity), and stores them internally. Software PC208W by Campbell Scientific Inc. is used to pre-condition the raw data, and convert it to a format compatible with the CMS software. The data is scaled to a 0 to 5 V range output, which is generated by a Campbell Scientific,

Comment [E.R.P4]: K.H. McDaniel, Real time psychrometric data collection, Mining engineering, October 1998, p. 74 - 77

Inc. SDMA04 analog output module. This unit can send four 0 to 5 V signals to the CMS based on a 0 to 5 V unit input signal from the PC208W software. Up to sixteen units can be linked in a series. These units are equipped with a Hathaway XZ2-DJ 0 to 5 V, 4 to 20 mA signal converter. The 0 to 5 V dc signal output from the SDMA04 was transformed into a 0 to 1 V dc signal appropriate for input to the LPU. The LPU transmits the signal throughout the underground facility to the CMR on the surface.

Figure 4.1 shows a simplified schematic of the underground ventilation system showing the relative location of the Mine Weather Stations as well as the airflow sensor locations.

4.3 Monitoring system calibration

The Mine Weather Station units were tested for accuracy against both the final signal reading in the CMS and a calibrated hand-held measurement device. To guarantee that the LPU/CMS system was functioning properly prior to connecting the WMSs, each outcome within the LPU was tested and the corresponding signal in the CMS was verified. Signals of 0 to 5-V dc were sent to verify the upper and lower range for each signal.

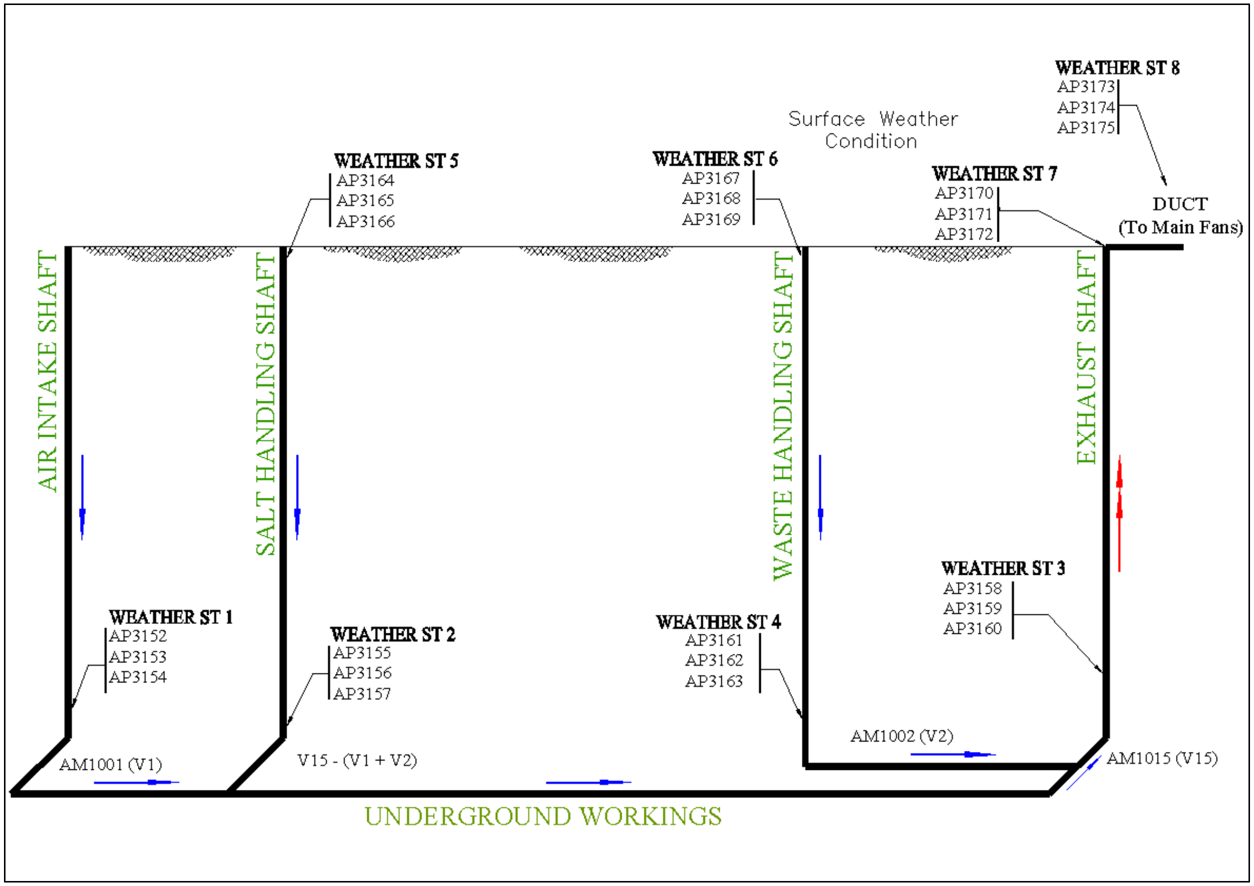

Figure 4.1 Simplified ventilation diagram showing the remote sensor locations.

According to McDaniel (1998), the signals transmitted were received in the CMS with greater than 99.5% accuracy in all cases. Then the actual outputs (0 to 5-V dc) were verified for each signal. This signal was recorded by the Campbell CR10 in the CMS with greater than 95% accuracy in all cases. In addition, the measured value was checked against a handheld instrument. A Solomat 500E multiprobe meter measured temperature and relative humidity, and the pressure was measured by a Setra, Model 370 digital pressure gage. The correlation between the values recorded by the Campbell and the handheld instrument was above 95% for most cases. This correlation was also greater than 90% in cases where the handheld instruments could not be held close to the sensors because the operator would have been exposed to hazardous conditions.

4.4 Database

The final output of the data acquisition procedure is an ASCII file containing the measurements of each Mine Weather Station, (dry bulb temperature, relative humidity and barometric pressure) and airflow measurements at different points.

The data was collected in the English units system and later converted to the SI system. For conversion to metric units the following apply:

Temperature Conversion: Fahrenheit to Celsius degree

$$T^{o}C = \frac{5}{9}(T^{o}F - 32)$$

Barometric pressure: inches of mercury to Pascal (Wolski).

Comment [E.R.P5]: Ask where this comes from. Barometric pressure conversion for a non constant Dry bulb temperature

$$P_{Pa} = \frac{3.386488 \cdot 1000}{1 + 0.18182 \cdot 10^{-3} \cdot T_d + 0.78 \cdot 10^{-8} \cdot T_d} \cdot P_{Hg}$$

Airflow: ft^3/s to m^3/s

$$Q = Q_E \cdot \frac{1000}{60 \cdot 35.3166672}$$

Chapter 5

SALT ROCK PROPERTIES

Geomechanical properties of salt deposits fit the requirements for nuclear waste storage. The appropriate characteristics are:

- Stable geological conditions
- Absence of ground water
- Salt rock hardness
- Fracture healing

These first three considerations are similar to a problem in any mining design and operation in salt, except that this design optimizes stability rather than economical extraction. Moreover, the last consideration involves the property of rock salt to creep sufficiently after closing a storage area and encapsulate the waste. The natural barrier provided by rock salt could act as an encapsulated system contrary to other host rock types. Due to the very low porosity and the high ductility, this prevents the presence of open joints. Considering these salt properties, waste encapsulation can perhaps be enhanced by back filling the storage rooms with the mined crushed salt rock, and allowing cementation to occur with time (Hardy, 1984).

Comment [E.R.P6]: H. Reginald Hardy, Jr and Michael Langer, The mechanical behavior of salt, Precidings of the first conference, Transtech publications, 1984, p. 681 - 682

The large volume of air flowing through the facility has the potential of evaporating or condensing large amounts of water. Salt rock can store or release large quantities of moisture from its lattice, which have long term effects on critical rock properties. Therefore, it is important to know the moisture balance for the effects it may have on geomechanical properties.

Estimating psychrometric and thermodynamic properties of the air is possible using CLIMSIM, software developed by Mine Ventilation Services Inc. These properties are largely affected by material properties and the type of airway that is to be analyzed. This software requires several material properties such as density, specific heat, thermal conductivity, and thermal difusivity as input for the calculations. At the WIPP site, the airway walls are generally composed of salt rock, therefore, some salt properties are listed in Table 5.1

Table 5.1 Salt rock physical properties used in CLIMSIM

		Source	
Item	**Symbol**	**Kaufmann (1960)**	**J.N. Sweet (1980)**
Density, gr/cm^3	ρ	2.12 - 2.209	2.1
Specific Heat, J/kg	C_r	853	890
Thermal Conductivity, W/m-K	K	6.97	3-6
Thermal difusivity, m^2/s	α_r		2.3 x 10^{-6}

Comment [E.R.P7]: Kaufmann, Dale Wilmer, Sodium chloride: the production and properties of salt and brine, New York Reinhold Pub. Corp 1960 p. xxxxx

Comment [E.R.P8]: Sweet, J. N. and J. E. McCreight, "Thermal conductivity of Polyhalite and Anhydrite on Rock Salt from the Site of the Propoesed Wates Isolation Pilot Plant, SAND80-0799, Sandia National Laboratories, Albuquerque, New Mexico 87185, May 1980.

CLIMSIM is used to compare results with the quality of psychrometric subroutines used with actual data in moisture balance, which is explained later in Chapter 9.

Chapter 6

PSYCHROMETRIC THEORY

Psychrometry is the science dealing with atmospheric properties (McPherson, 1992). In general, Psychrometrics can be defined as the study of the physical and thermodynamic properties of air-water vapor mixtures.

Comment [E.R.P9]: Malcom J. McPherson, Subsurface ventilation and Environmental engineering, Chapman & Hall, 1993, p. - 491

The atmosphere is a mixture of several gases, mainly oxygen and nitrogen. Under normal conditions, the percentages of these gases do not vary significantly. This statement demonstrates the principle of thermodynamics where all these gases combined are treated as one gas called "air" (Barenbrug, 1995). In addition to the above-mentioned gases, the atmosphere can contain a certain amount of water vapour. Concentrations of water vapour can vary considerably from place to place and with time. In ventilation engineering, we speak of dry air, humid air, or saturated air, but air can never be dry in normal atmospheres. The normal atmosphere is humid or saturated. If the atmosphere is dry, it consists of dry air alone. If the atmosphere is humid, it consists of, besides air, some water vapour. If the atmosphere is saturated, it contains besides air, the maximum possible amount of water vapour for that condition. The state of a substance such as air is altered if it undergoes a process like compression or expansion, cooling or heating, humidifying or dehumidifying. Because of these processes, properties such as volume, pressure, temperature, and moisture content are also altered.

Comment [E.R.P10]: A..W.T. Barenbrug , Psychrometry and psychrometric charts, 1955, p. 1

6.1 Governing laws

The two governing laws, which are important in understanding the relationships between psychrometric properties, are Dalton's Law and the Ideal Gas Law (Bohnhoff, 1994).

Comment [E.R.P11]: Dave Bohnhoff, University of Wisconsin, Course Manual and Lecture Notes Agricultural structures & environment for AgEngr 351, Spring Semester 1994

6.1.1 Dalton's law

Dalton's Law of Partial Pressures: each gas in a mixture creates pressure as if the other gases were not present. The total pressure is the sum of the pressures created by the gases in the mixture.

$$P_{Total} = P_1 + P_2 + P_3 + \ldots + P_n$$

Where:

n = the total number of gases in the mixture

The only requirement is that the gases do not interact in some chemical fashion, such as reacting with each other.

The pressure each gas exerts in mixture is called its partial pressure.

6.1.2 Ideal gas law

Combination of the three empirical gas laws $PV = k$, $V = k'T$, *and* $V = k''n$ (Boyle's law, Charles' law, and Avogadro's hypothesis) leads to the ideal gas law which is usually written as:

$$PV = nRT$$

The universal gas constant *R* has a value, which depends only upon the units in which the pressure and volume are measured. The best available value of the universal gas constant is 8.3143510 J/mol K, or 8.3143510 kPa L/mol K.

6.2 Basic psychrometric relationships

Most of the applications of psychrometric relationships assume that the air is a mixture of perfect gasses, and are treated as such. Expressing the quantity of water vapour contained within a given air stream is preferable in terms of mass (kg) rather than volume (m^3). Changes in pressure and temperature cause the volume of air to change as it flows along the airway. The most commonly used terms to describe air-water vapour properties are temperature and humidity.

- Temperature: There are actually three measures of air temperature that should be considered; these are:

1. Dry-bulb temperature: Temperature as read from a common thermometer.

2. Wet-bulb temperature: Temperature is measured by placing a common mercury thermometer, with a water-moistened wick covered bulb, into a fast moving stream of ambient air. Evaporation of water from the wick cools the bulb, the amount of cooling is proportional to the evaporation rate, which in turn is inversely proportional to the amount of water in the air).

3. Dewpoint temperature: Temperature at which condensation will occur as air is cooled at a constant pressure and humidity ratio.

- The moisture content in air is often described by relative humidity. Other terms that relate to moisture content are: humidity ratio, specific humidity, degree of saturation, vapor pressure and wet-bulb depression. An additional air property that is important in the psychrometric studies is the specific volume.

1. Relative humidity: Relative humidity, RH, is defined as the ratio of the mole fraction of water vapor in a moist sample of air to the mole fraction in a saturated sample at the same temperature and pressure. By use of the perfect gas law, this can be expressed as the ratio of the actual vapor pressure to the vapor pressure of saturated air at the same temperature. A close approximation in ordinary terms is the ratio of vapor present in the air to the maximum amount of vapor that the air can hold at a given temperature. Relative humidity is expressed as a percentage.

2. Specific Humidity: The specific humidity is the mass of water vapor in the air to the mass of dry air (Hartman, 1982). This may also be called the moisture content or mixing ratio. Specific humidity is not affected by a temperature change unless it drops below the saturation temperature.

Comment [E.R.P12]: H.L Hartman, Mine ventilation and air conditioning, Krieger Publishing company, 1982, p.15

3. Degree of saturation: The ratio of the actual density of water vapor in the air to the density of saturated water vapor, at the same dry-bulb temperature.

4. Vapor pressure: is the independent pressure exerted by the water vapor in the air. The vapor pressure is proportional to the specific humidity. The natural tendency for pressures to equalize will cause moisture to migrate from an area of high vapor pressure to an area of low vapor pressure. The saturation vapor pressure varies with temperature.

5. Wet-bulb depression: Difference between the dry-bulb and wet-bulb temperatures. The temperature is depressed by evaporative cooling of the wet bulb. The greater the difference between the amount of water in the air and the saturation water capacity the more rapid the evaporation and thus the greater the temperature depression.

- Specific volume: The volume of a mixture per kilogram of dry air (inverse of density)

The relationships of these properties, (McPherson, 1992) may be described by equations 6.1 to equation 6.8 as follows:

Comment [E.R.P13]: Malcom J. McPearson Subsurface Ventilation and Environmental Engineering Chapman and Hall, 1993 p. 491-519

- Saturation vapour pressure at the air temperature, Pa:

$$e_{sd} = 610.6 \cdot e^{(17.27 \cdot \frac{T_d}{237.3+T_d})} \qquad (6.1)$$

- Partial pressure exerted by the water vapour (Dalton's Law of partial pressure for prefect gasses), Pa:

$$e = e_{sd} \cdot \frac{RH}{100} \qquad (6.2)$$

- Specific humidity (Mass of water vapour, moisture content), kg/kg (dry air):

$$X = 0.622 \cdot \frac{e}{P - e} \tag{6.3}$$

- If we have a closed vessel of volume V (m^3) containing 1-kg of dry air at a pressure P_a in Pa and at a temperature T_K in Kelvin, and if we inject X kg of water vapour at the same temperature, the pressure within the vessel will increase to:

$$P = P_a + e \tag{6.4-a}$$

Solving for Pa

$$P_a = P - e \tag{6.4-b}$$

- Apparent specific volume based on 1-kg of dry air, m^3/kg:

$$V_{mapp} = 287.04 \cdot \frac{T_K}{P_a} \tag{6.5}$$

- Apparent density, kg/m^3 (dry air)

$$\rho_{mapp} = \frac{1}{V_{mapp}} \tag{6.6-a}$$

Actual density, kg/m^3 (humid air)

$$\rho_m = \rho_{mapp} \cdot (1 + X) \tag{6.6-b}$$

- Mass flow rate, kg/s:

$$M = Q \cdot \rho_m \tag{6.7}$$

- Finally, the amount and the rate of evaporation/condensation or absorption between two points X_1 and X_2 (inlet and outlet respectively) is calculated as follows, kg/s (l/s):

$$R = M \cdot (X_2 - X_1) \tag{6.8}$$

The measured variables are dry bulb temperature (T_d), relative humidity (RH), barometric pressure (P), and airflow rate (Q). All temperature and pressure variables are measured in Celsius degrees and Pascal, relative humidity is measured in %, and airflow rate in m^3/s. A positive value (+R) will indicate that ventilating air is removing (evaporating) moisture from the mine between points 1 and 2. On the other hand, a negative value (-R) will indicate that ventilating air is depositing (condensing) moisture on the exposed surfaces, moisture that might be absorbed by the salt rock. Moisture absorption is more likely to happen in freshly exposed walls of the salt rock.

The weather condition measurements at the surface are expected to have a great influence in moisture quantification. Diurnal and nocturnal effect on the temperature as well as seasonal effect throughout the year is expected to cause the same effect of a cycling period in the moisture quantification. The most influencing parameter is surface temperature, which is shown in Figure 6.1 and Figure 6.2 for the diurnal/nocturnal and seasonal variations.

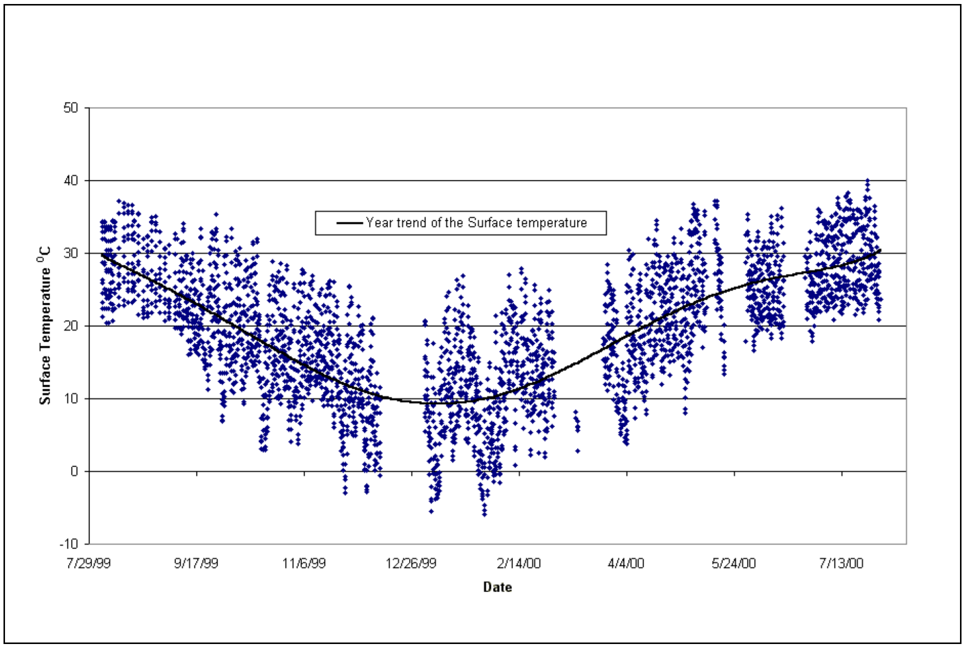

Figure 6.1 Seasonal variation of the surface temperature at WIPP site

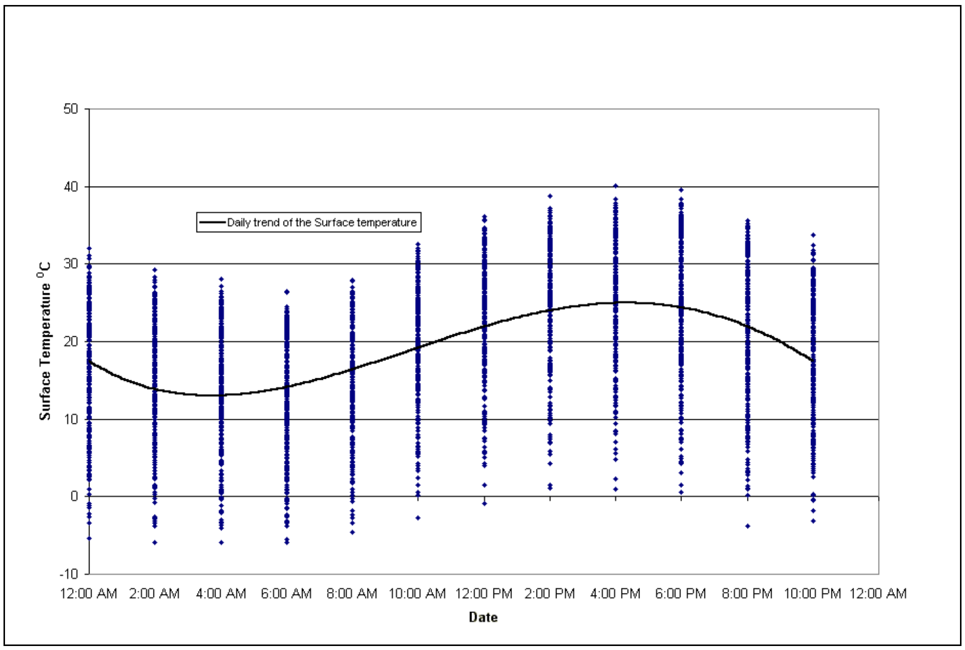

Figure 6.2 Diurnal/nocturnal variation of the surface temperature at WIPP site

Chapter 7

MULTIVARIATE STATISTICS

Multivariate statistics provide the ability to analyze complex sets of data providing means for analysis where there are many independent (IVs), and possible dependent variables (DVs) which are correlated to each other to varying degrees. The availability of software application programs such as MINITAB, that can handle the complexity of large multivariate data sets, has increased and popularized the use of multivariate statistics. Assessment of results is iterative. Univariate analysis ignores the correlation or interdependence among variables and may sometimes lead to incorrect interpretations (Repoff, 1983).

Comment [E.R.P14]: Thomas P. Repoff, Multivariate Statisctical Analysis of Atmospheric Diffusion and Transport Processes', T-2745, 1983, p. 40

7.1 Multivariate general linear hypothesis

The theory of multivariate analysis assumes that the joint probability of the random variable is a multivariate normal distribution. The procedures involved with multivariate analysis are based on the same linear model as analysis of variance, discriminant analysis, principal components analysis or multiple regression analysis models. Linear models are based upon lines; more generally, they are based on linear planes or surfaces.

7.2 Linear regression analysis

Linear regression analysis is a set of statistical techniques, which allow one to assess linear relationships between one dependent variable (DV) and several independent variables (IVs). Multiple regression is an extension of bivariate regression in which several IVs are combined to predict the DV. Linear regression analysis may be assessed in a variety of manners, among which partial and multiple regression and correlation analysis is the most common.

7.2.1 Partial regression and correlation

Partial regression and correlation isolates the specific effect of a particular independent variable, controlling for the effects of other independent variables, relationship between pairs of variables, while recognizing the relationship with other variables.

7.2.2 Multiple regression and correlation

In this study, the problem is defined as to quantify moisture balance and construct a mathematical model to estimate this process at different areas of the WIPP facility. This implies that the response (DV) in our models is the rate of condensation or evaporation occurring between two points. The suggested variables (IVs) are: air temperature, relative humidity, barometric pressure at the inlet of the airway as well as the mass flow rate measured at this location.

The general multiple regression model that might describe the relationship between the variables indicated above is:

$$Y = \beta_0 + \beta_1 X + \beta_2 X_2 + \ldots + \beta_4 X_4 + \varepsilon$$

Where **Y, X_1, X_2, … X_4** represent the response and the 4 independent variables, and β_0, β_1, … β_4 are unknowns to determine (the beta coefficients) and ε is a random error component. The errors are assumed to have a mean equal to zero and an unknown variance σ^2 meaning that the value of the error does not depend on the value of any other error.

According to Montgomery (1991), the main assumptions for any linear regression analysis are:

Comment [E.R.P15]: Douglas C. Montgomery, Elizabeth A. Peck, Introduction to linear regression analysis, Second edition, John Wiley & Sons, Inc, 1991.

- The relationship between the dependent and independent variables is linear
- The error ε has a zero mean and a constant unknown variance σ^2
- The errors are uncorrelated and normally distributed

The method of least squares is used to estimate the beta coefficients. That is β_0, β_1, … β_4 will be estimated so that the sum of the squares of the difference between the observations Y_i and the straight line is a minimum. The fitted simple linear regression model will be:

$$\hat{Y} = \hat{\beta}_0 + \hat{\beta}_1 X + \hat{\beta}_2 X_2 + \ldots + \hat{\beta}_4 X_4$$

The difference between the observed value and the corresponding value is a residual, that is:

$$e_i = Y_i - \hat{Y}_i$$

Residual play an important role in investigating the adequacy of the fitted regression model and in detecting departures from the basic assumptions.

If the true relationship between the response and the independent variables is unknown, we can still rely on this experimental linear model. This model might sometimes result unrealistic, but at least would reproduce the main features of the response under study (Draper, 1980).

Comment [E.R.P16]: N.R. Draper and H. Smith, Applied regression analysis, Second edition, John Wiley & Sons, Inc, 1980

7.3 Measures of model adequacy

Evaluating model adequacy is an important part of a multiple regression problem. The most common methods for measuring model adequacy are:

- Coefficient of multiple determination R^2: usually described as the reduction in the variability of ***Y*** obtained by using the regressor variables. As in the case of a simple regression analysis, R^2 value is within 0 and 1. However, this does not necessarily imply a good fit in the model. Adding a regressor will increase R^2 regardless of whether or not the additional regressor contributes to the model.

- Residual plots: the residual e_i from the multiple regression model play an important role in judging model adequacy. Normal probability plots of the residuals, plot of the residuals versus order of the data as well as the plot of the residuals against the fitted values are used to detect non-normality and for identifying outliers. An outlier is an extreme observation. Residuals that are considerably larger in absolute value than the others (three or four standard deviations from the mean) can be considered and treated as outliers. The reasons for outliers should be carefully investigated and non-statistical evidence should be provided before the outlier is removed.

The development of the mathematical models using this theory is explained in Chapter 9.

Chapter 8

ANALYSIS OF ERROR PROPAGATION

The analysis relies on the monitoring system calibration described in Chapter 4. This statement implies that the uncertainty in the system measurements was less than 5% at the time of calibration. Further analysis of errors in measurements is necessary to completely define sources of errors and determine the effects on the analysis, results and conclusions.

8.1 Instrument resolution

The HMP35C temperature/relative humidity probe contains a Vaisala capacitive relative humidity sensor and a Fenwal Electronics UUT51J1 thermistor. Resolutions are reported in table 8.1.

The FloSonic is a microprocessor based ultrasonic airflow sensor. During calibration tests handheld anemometer measurements were different from the FlowSonic by approximately 3%.

The PTA-427 barometer uses Vaisala's patented silicon capacitive pressure sensor. A linear output of 0 to 5 V is proportional to 800 to 1060 millibars. The transmitter is temperature compensated over an operating range of -40 to 60°C.

Specification described by the manufacturers are summarized on Table 8.1

Table 8.1 MWS and airflow sensor specifications

Sensor	Manufacturer	Signal type	Resolution	Range

HMP35C Temperature Probe	Campbell Scientific, Inc.	Analog 0 to 5 V	± 0.4 °C (± 0.72 °F)	–35 to 50°C and 0 to 100%
HMP35C Relative humidity Probe	Campbell Scientific, Inc.	Analog 0 to 5 V	± 0.2 %	–35 to 50°C and 0 to 100%
PTA427 Barometer	Campbell Scientific, Inc.	Analog 0 to 5 V	± 0.5 mb (±0.0176 inHg)	80 to 106 kPa
FloSonic airflow sensor	El-Equip Inc	Analog 4 to 20 mA	± 3%	0.1 to 30 m/s

8.2 Measurement errors

Using fifteen-minute intervals in the calculations would not have been appropriate since climatic conditions do not change much over such a short period. A two hour interval was chosen considering that twelve points per day is good enough to depict significant changes in the climatic conditions. If we were to use average values of the measurements for a period of two hours (eight readings at fifteen-minute intervals) we would not be considering the change of these variables over this period. The variables that are expected to change the most are surface temperature and relative humidity (see Figure 8.1) because of their cycling character during the course of the day. The variances calculated using the average of these parameters (temperature and relative humidity) over the two-hour interval are high. The expected contributions to the variance of the results are likely to have the same order of magnitude, which would result in an unreasonable analysis.

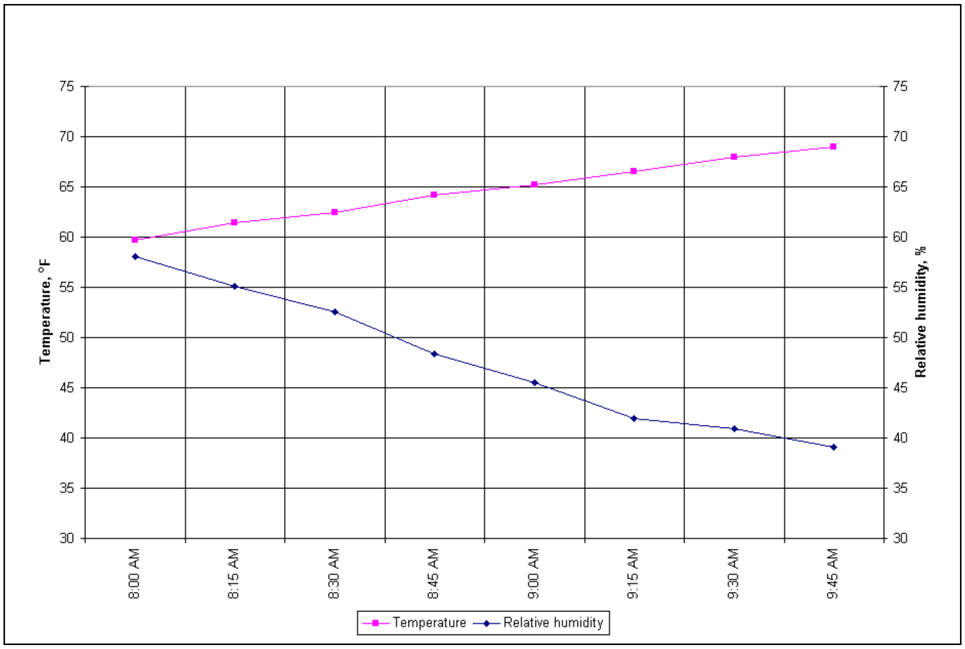

Figure 8.1 Surface temperature and relative humidity variation during a two-hour interval

To test this statement, average values for temperature, relative humidity, barometric pressure at the inlet and outlet, as well as airflow were used in the calculation of moisture balance at the AI shaft (see Table 8.2).

Table 8.2 Average values used for error analysis in moisture balance for the AI shaft

Time	Air, KCFM	AI Collar			AI Base		
		T, °F	RH, %	BP, in Hg	T, °F	RH, %	BP, in Hg
8:00:00	285.522	59.731	58.032	26.489	74.769	38.733	28.546
8:15:00	283.539	61.390	55.054	26.489	74.777	38.495	28.546
8:30:00	284.119	62.472	52.515	26.489	75.249	37.848	28.546
8:45:00	279.633	64.159	48.330	26.489	76.077	37.366	28.546
9:00:00	280.243	65.163	45.513	26.489	76.281	36.530	28.546
9:15:00	281.891	66.480	41.948	26.489	76.940	35.480	28.546
9:30:00	281.738	67.940	40.884	26.489	77.162	34.741	28.546
9:45:00	282.532	68.929	39.102	26.489	77.821	33.746	28.546
Mean	282.402	64.533	47.672	26.489	76.135	36.617	28.546
St_Dev	1.965	3.217	6.997	5.1E-07	1.138	1.818	5.1E-07
Var	3.861	10.349	48.952	2.6E-13	1.295	3.306	2.6E-13
N	8	8	8	8	8	8	8

As it was expected, temperature and relative humidity at the surface are considerably large. Although, these variables are more constant in the underground environment they are still of some concern.

Propagation of error or transmissions of variance formulas were used to further describe how variability or error would be propagated or transmitted through exact mathematical function formulas in the moisture balance quantification. These error propagation formulas are useful if no other means of estimating this analysis are available. Vardeman (1994) considers that these equations are at least o

Comment [E.R.P17]: Stephen B. Vardeman, Statistics for engineering problem solving, PWS publishing company, Boston 1994, p. 257

the right order of magnitude and better than not having any usable approximation. These equations are:

$$EU \approx g(EX, EY \ldots EZ)$$

$$Var\,U \approx \left(\frac{\delta g}{\delta x}\right)^2 Var\,X + \left(\frac{\delta g}{\delta y}\right)^2 Var\,Y + \ldots + \left(\frac{\delta g}{\delta z}\right)^2 Var\,Z$$

Where:

EU is the mathematical relation

$\left(\frac{\delta g}{\delta x}\right)^2 Var\,X + \left(\frac{\delta g}{\delta y}\right)^2 Var\,Y + \ldots + \left(\frac{\delta g}{\delta z}\right)^2 Var\,Z$ are the variance contribution of variables ***X***, ***Y*** and ***Z*** respectively

Error propagation associated with the calculations was performed from the initial steps, which are the conversions of units to the final result R, the rate at which moisture is being evaporated or picked up by the airflow. The analysis was performed for two cases:

Case 1 is an average over two hours, and case 2 is selecting a singly point every two hours.

1. The total variances for the variables T, RH, BR, and Q are the sums of the variances due to the sensors and the variances in the measurements. Variance contributions of the sensors are

considerably smaller than the variances in the measurements and could have been neglected in the error propagation analysis.

2. The same analysis was performed assuming variance contribution in the measurements is the result of only the instrument resolution and no error are associated with the measurements.

Table 8.3 summarizes the variance contribution that each of the calculated properties has onto the result R for both cases.

Table 8.3 Variance contribution of the variables associated with moisture balance calculation

Variable	**Variance contribution**	
	Case 1	**Case 2**
M	4.806×10^{-7}	1.983×10^{-7}
X_2	5.588×10^{-3}	7.482×10^{-4}
X_1	3.842×10^{-2}	7.142×10^{-4}
Total	4.402×10^{-2}	1.467×10^{-3}
σ_R	0.210	0.0383

The standard deviation for case 1 is the result of including the variance due to averaging values plus the variances due to the instruments. On the other hand, the standard deviation for case 2 is the result of variances due to instrumentation only. Clearly, the results assuming the only source of error is in the instrumentation are more acceptable. Using average values of the fifteen-minute intervals over any period would not be appropriate because of the large variances induced to the result.

Chapter 9

DEVELOPMENT OF THE MATHEMATICAL MODELS

Three basic steps where followed in the construction of the predictive mathematical models. They are:

1. Data collection
2. Data reduction
3. Model selection

9.1 Data collection

Data from the eight weather stations and air velocity sensors were collected for a period of one year, starting August 1999 through July 30 2000 at intervals of 15 minutes. This step was described earlier in Chapter 4

A Partial check of the quality of the data was performed by comparing surface temperature collected at Station 8, which measures surface climatic conditions against temperature collected at the Carlsbad Airport (Figure 9.1). Temperature at the Carlsbad Airport was provided by the National Oceanic and Atmospheric Administration (NOAA).

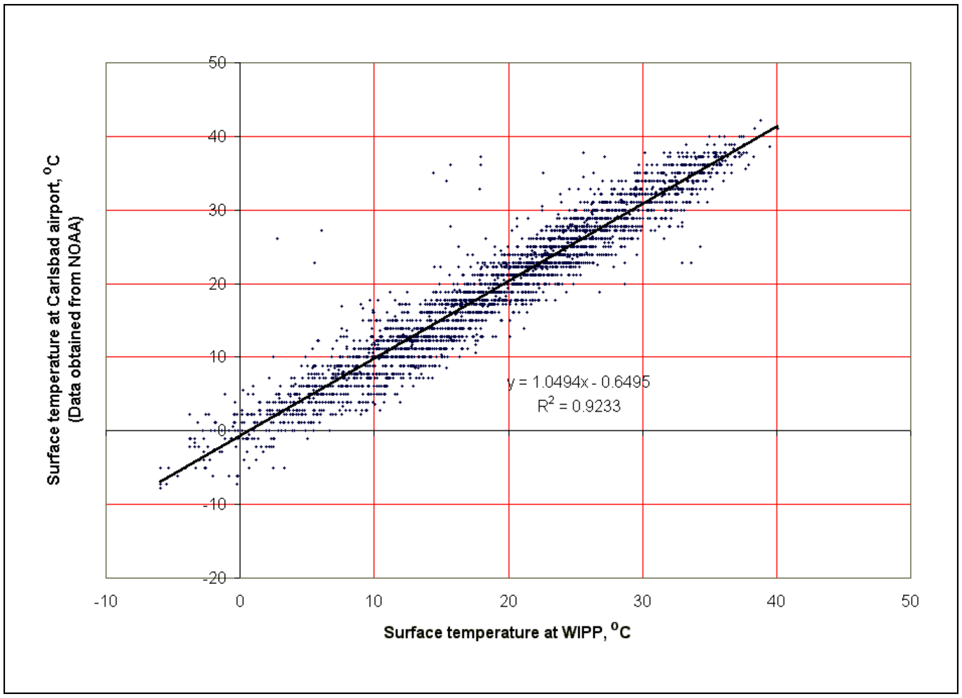

Figure 9.1 Surface temperature at WIPP and Carlsbad airport

From Figure 9.1, we can conclude that the surface temperature readings at the WIPP site are acceptable due to the high correlation between both sets of data. It is assumed that the rest of the sensors at each of the Weather Stations are as reliable as these Stations.

Along with the reduction of the data, subroutines were developed in Microsoft Excel for calculation of the rate of condensation/evaporation or absorption (R, in l/s) using the equations described in Chapter 6 (equations 6.1 through 6.8). Stations used as intake and outlet conditions for the five areas of interest are summarized in Table 9.1

Table 9.1 Weather stations used in the psychrometric calculations

Area	**Weather Station**	
	Intake	**Outlet**
AI Shaft	7	1
SH Shaft	7	2
WH Shaft	6	4
ES Shaft	3	8
UG Workings	1 and 2	3

Weather Station 7 is used for both, AI and SH intake conditions, because both Station 7 and Station 5 ideally should have the same dry bulb temperature, relative humidity and barometric pressure values. Figure 10.1 compares dry bulb temperature for these two stations. Even though MWS 5 is at the collar of the SH shaft, there is no heating or cooling process in the air going through this shaft thus, this station reads the same conditions of MWS 7.

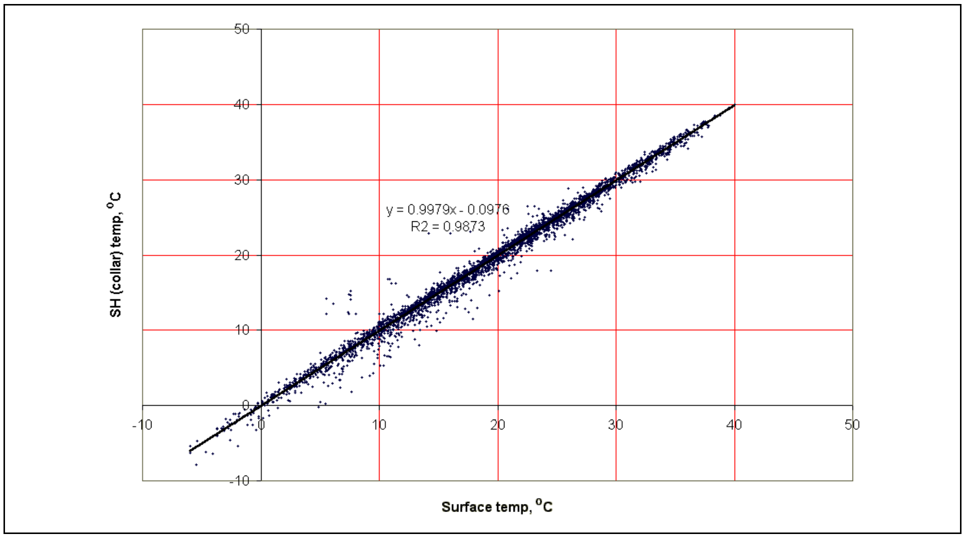

Figure 9.2 Temperature comparison at Weather Stations 5 and 7

9.2 Data reduction

Prior to the analysis, it is important to analyze the data, checking for extreme values, clustering, and other peculiarities in the data, ensuring that the underlying assumptions of multiple regression analysis are satisfied. Table 9.2 summarizes the steps followed for an appropriate screening of the proposed data (Tabachnick and Fidell, 1989). The order of the screening is important at the earlie steps, influencing decisions to be taken at later steps. For example: if the data are both non-normal and have outliers, a decision to either delete the values or transform the data has to be made. Transformations are usually preferred as they typically reduce the number of outliers, and improve

Comment [E.R.P18]: Tabachnick, B., and L. Fidell, 1989; Using Multivariate Statistics , (Harper & Row Publishers, New York, 746p.)

normality, linearity, and homoscedasticity. Screening of the data will assist in isolating data peculiarities and will allow it to be adjusted for further multivariate analysis.

Table 9.2 Checklist for screening data

	Task
1	Inspect univariate descriptive statistics for accuracy of input
a.	Identify out-of-range values, be aware of measurement scales
b.	Plausible means and standard deviations
2	Evaluate amount and distribution of missing data
3	Identify and deal with non-normal variables
a.	Check skewness and kurtosis, probability plots
b.	Transform variables (if desirable)
c.	Check results of transformations
4	Identify and deal with outliers

This checklist isolates essential decision points, which need to be assessed to prevent poor data from being used in the analysis. Consideration and resolution of problems encountered in the screening of a data set is necessary to ensure a robust statistical assessment.

An initial reduction of the proposed data was accomplished by observing that climatic conditions do not change considerably over a period of fifteen minutes, thus a sampling interval of two hours was chosen. This interval of two hours reduced considerably the size of the database from over 30,000 points to approximately 4,000 points.

The airflow readings at the AI shaft were adjusted by multiplying them by a factor of 1.08 to compensate for the air leakage at bulkheads 402 and 403 (see Figure 3.1). This adjustment is based on the data collected for the period of August 1999 to August 2000 and the MVS (Mine Ventilation Services Inc.) May 1999 WIPP ventilation study. MVS reported 73 percent of total air flowing through the AI shaft. Total air is measured at ES shaft. Using data collected from August 1999 to August 2000 this percentage was calculated to be about 67 percent (See Figure 9.3).

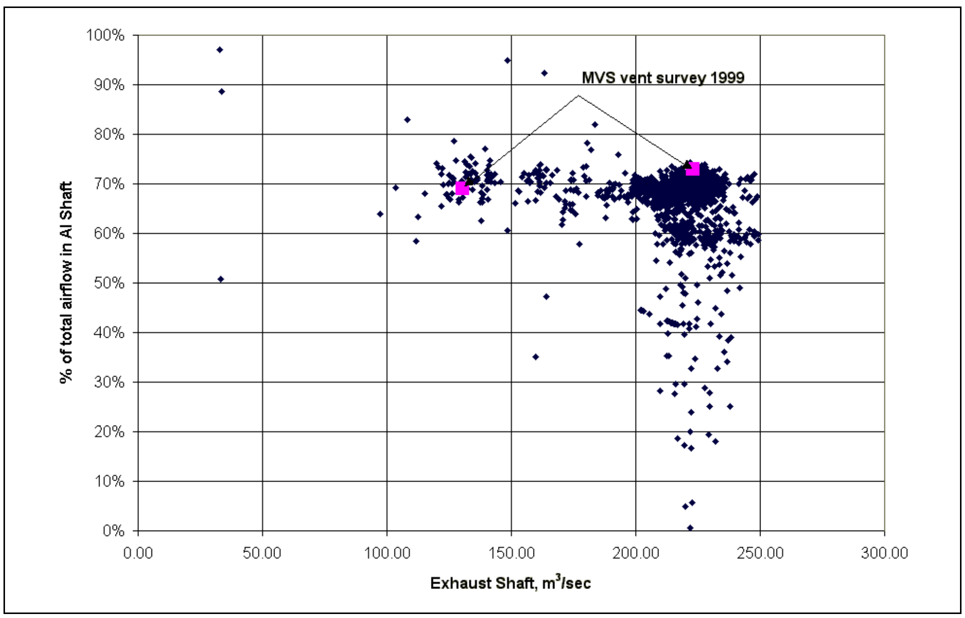

Figure 9.3 Percentage of total airflow at the AI shaft
(not including leakage at bulkheads 402 and 403)

However, this proportion is not considering the airflow leakage at the indicated bulkheads. The airflow adjustment factor at the AI shaft that takes into account leakage at bulkheads 402 and 403 is calculated as follows:

$$Airflow\ rate\ adjustment\ \ factor = 1 + (1 - \frac{67}{73})$$

$$Airflow\ rate\ adjustment\ \ factor = 1.08$$

In a similar manner, proportions at the other shafts where determined. Figure 9.4 shows the proportions of airflow rate of the AI, SH, and WH shafts compared to the ES shaft. These proportions were used to approximate missing values at these areas. For instance, the proportion of airflow rate at the WH shaft is approximately 30/220 or about 14 percent.

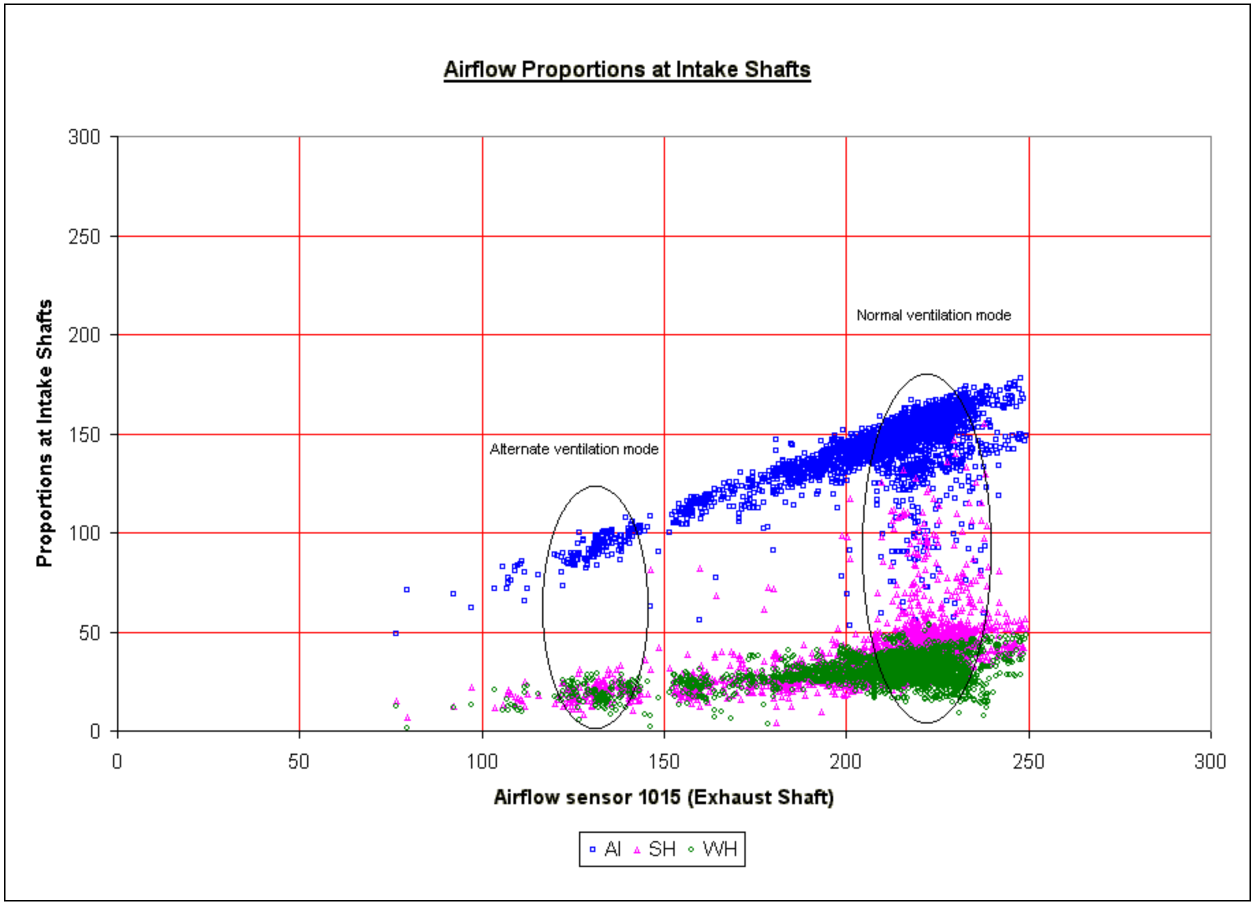

Figure 9.4 Airflow proportions at the intake shafts (m^3/s)

As it is shown on Figure 9.3 and Figure 9.4, the airflow rate at each of the shafts were broken out as percentages of the total airflow measured at the ES shaft. These percentages are summarized on Table 9.3 comparing values extracted from MVS, Inc. 1999 Mine ventilation plan, for both, normal and alternate modes of operation. Proportions at the AI shaft where already adjusted.

Table 9.3 Percent of airflow at WIPP shafts

Shaft	Normal Mode			Alternate mode		
	m^3/s	%		m^3/s	%	
	MVS	MVS	1999 2000	MVS	MVS	1999 2000
AI	160.	73	72	89	69	68
SH	29	13	15	12	10	12
WH	31	14	13	27	21	20
ES	221	100	100	129	100	100

9.2.1 Inspecting univariate descriptive statistics

Additional data reduction was accomplished by inspecting univariate descriptive statistics of the data. Summary statistics such as mean, median, standard deviation, minimum, maximum of the proposed data are included in Appendix A. Summary statistics allowed the identification of out of range values. The WIPP facility is an operating facility, with all the activity underground, the sensors are expected to experience temporary outages or output unreasonable data.

9.2.2 Evaluate the amount and distribution of missing data

It is understood, as missing values to periods over which zero values from the sensors were collected in the data or when readings from the sensors were reported repeatedly for a considerably period such as 12 hours. Two options were suggested for the case of missing data:

1. Estimating the missing values or

2. Deleting missing values from the analysis.

9.2.2.1 Estimating missing values

Unlike the case of small data sets, with nonrandom distribution of missing values causing serious problems, the proposed data set is large enough to discard the missing points without causing significant problems. Still, before discarding these missing points and attempt to solve this problem was carried on.

Estimating missing values was the first option to solve this problem. This was possible when data was available for interpolation or proportions were evaluated such as the case of the airflow at the shafts as described at the beginning of this section (Data reduction).

Airflow at the SH shaft was not measured directly but it was possible to compute it by using the readings at the other intakes and the exhaust shafts using the following equation:

$$V_{SH} = V15 - (1.08 \cdot V1 + V2)$$

Where:

V15: airflow sensor at ES shaft

V1: airflow sensor at the AI shaft

V2: airflow sensor at WH shaft

9.2.2.2 Deleting missing values from the analysis

Deleting missing values was a second option prior to regression analysis. This was applied for periods longer than 12 hours, or where an estimation of the variable; using other data, was not possible. Again, zero or repeated values where treated as missing values. Some examples are periods in the months of August and November 1999 and March, April, May and June of the year two thousand. Table 9.4 summarizes all the periods that were deleted from the database based on this criterion.

Table 9.4 Significant periods deleted from the database

Date	From	To	Description
08/11/99	00:00:00	22:00:00	Zero readings or repeated values
08/13/99	00:00:00	22:00:00	
08/15/99	00:00:00	22:00:00	
08/17/99	00:00:00	22:00:00	

08/20/99	00:00:00	22:00:00	
08/22/99	00:00:00	22:00:00	
08/24/99	00:00:00	22:00:00	
08/26/99	00:00:00	22:00:00	
08/28/99	00:00:00	22:00:00	Zero readings or repeated values
08/30/99	00:00:00	22:00:00	
09/01/99	00:00:00	22:00:00	
09/03/99	00:00:00	22:00:00	
09/05/99	00:00:00	22:00:00	
09/06/99	00:00:00	22:00:00	
09/08/99	08:00:00	22:00:00	
03/01/00	14:00:00		Same readings for all these periods
Through			
03/24/00		16:00:00	
03/31/00	08:00:00	14:00:00	Bad airflow sensor readings
04/14/00	06:00:00	14:00:00	Bad airflow sensor readings
04/28/00	10:00:00	14:00:00	Bad airflow sensor readings
05/11/00	00:00:00		No readings from the sensors
Through			
05/14/00		22:00:00	
05/17/00	12:00:00	12:00:00	Bad airflow sensor readings
05/19/00	16:00:00		Same readings for all this period
Through			
05/29/00		22:00:00	
06/16/00	18:00:00	Through	Same readings for all this period
06/26/00		18:00:00	

The worst case was found for the month of March 2000, where two hundred seventy six (276) points were deleted. These points represent all the data for the entire month of March. The reason why these point were deleted is that all the sensors recorded the same value for this entire period. This problem could not be avoided since the data were being collected periodically and it was not possible to realize of the erroneous readings until the collection was completed at the end of the period.

9.2.3 Analysis with nonnormal variables

The underlying assumption of most multivariate analysis and statistical tests is multivariate normality. Multivariate normality is the assumption that all variables and all combinations of the variables are normally distributed. When the assumption is met the residuals are normally distributed and approximately independent, the differences between predicted and obtained scores (the errors) are symmetrically distributed around a mean of zero and there is no pattern in the errors. Screening for normality was undertaken using statistical and graphical methods examining skewness and kurtosis of the distributions summarized in Appendix A. The suggested transformations are attached in Appendix B.

9.2.4 Identification of outliers

Outliers are extreme values of one variable or a combination of variables caused by wrong measurements or unusual events. They have a strong influence on the calculation of statistics, these extreme cases were initially identified by examining scatter plots of the independent variables. The variable with most of these peculiar values is the airflow rate, which is used in the regression analysis in terms of mass flow rate ($M = \rho Q$). Figure 9.5 is a time series plot of the airflow rates at the intakes and exhaust shafts of the WIPP facility. Clearly, there were periods when the airflow rate was either larger or smaller than the estimated average value.

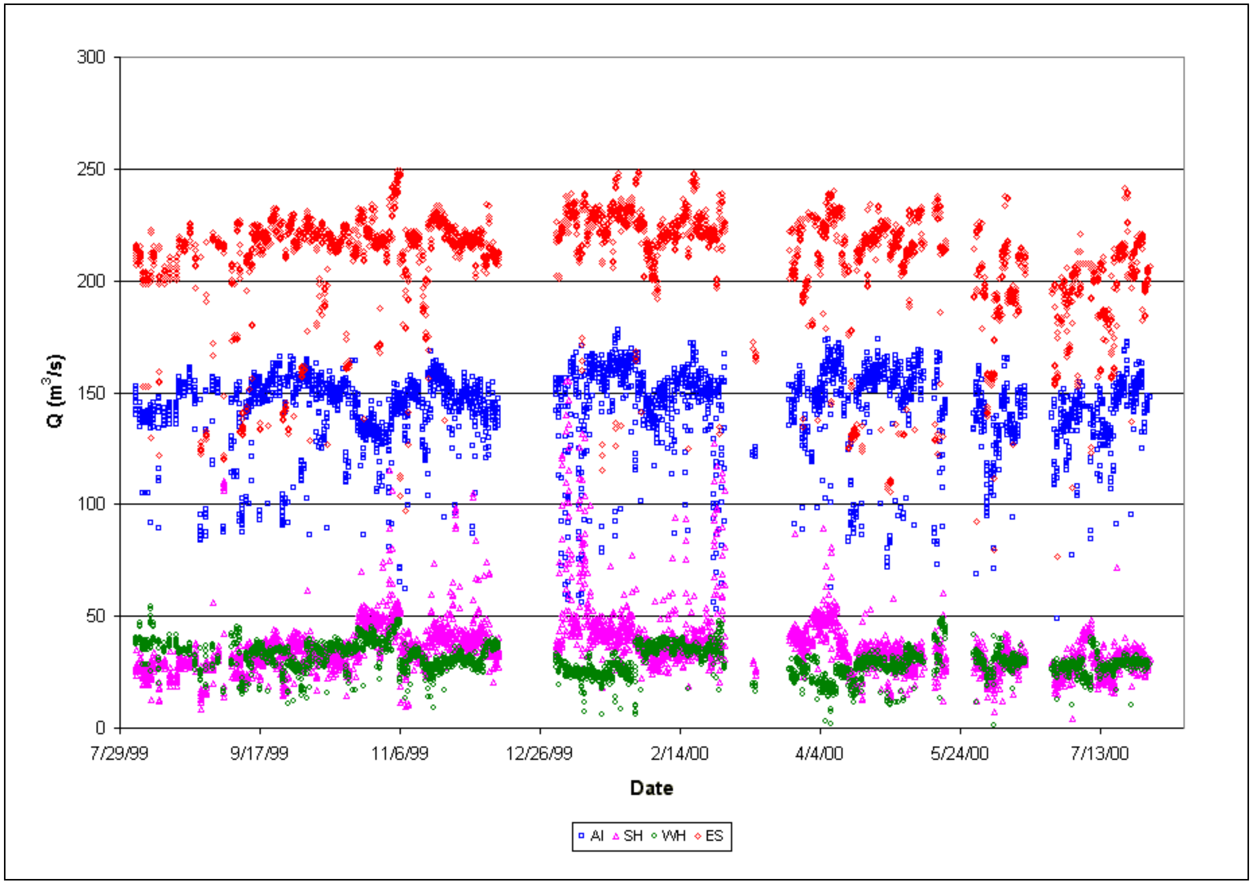

Figure 9.5 Airflow rate time series plot used to identify outliers in this variable
(Intake and exhaust shafts)

Further examination of the outliers was accomplished by plotting the expected values vs. obtained scores (predicted vs. actual). Deletion of these outliers was considered after failing to reduce them using transformations. The influence of these values was checked in the regression analysis results. Comparing models developed using data containing the outliers (referred as Model 1) and models developed with data that did not include these extreme values (referred as Model 2). Rows with the outliers identified are shown in Appendix C.

9.3 Model selection

Our mathematical linear models were developed using multiple linear regression analysis, method that was described earlier in chapter 7. An initial step in developing the models was to run the best subset regression using the response and the independent variables. The independent variables temperature, relative humidity, barometric pressure (T, RH, BP) are the airflow conditions at the inlet of each of the five areas (AI, SH, WH, UG, and ES). The airflow rate was expressed as mass flow rate (M) using the air density calculated at the same location where airflow rate was measured.

Surface dry-bulb temperature, relative humidity, barometric pressure and mass airflow are expressed as ***T***, ***RH***, ***BP*** and ***M,*** these variables at other locations e.g. ES shaft inlet conditions are expressed as $\boldsymbol{T_{ES}}$, $\boldsymbol{RH_{ES}}$, $\boldsymbol{BP_{ES}}$ and $\boldsymbol{M_{ES}}$. That is air dry-bulb temperature, relative humidity, barometric pressure and mass airflow at the ES shaft inlet.

Two cases were analyzed for model development for each of the five areas. The first case referred as Model 1 is the case when the regression equation was developed using all the data, including the outliers. On the other hand, the second case designated as Model 2, is the case when the regression analysis was performed with the outliers removed from the data. Table 9.5 and Table 9.6 summarize the resulting regression equations for each of the five areas in both cases.

Table 9.5 Linear regression equations developed for the AI, SH and WH areas

Area	Model	Equation	R^2 (%)
AI	1	$R_{AI} = -0.124 + 0.00617 \cdot T - 0.302 \cdot RH + 0.380 \cdot \sqrt{RH} - 0.228 \cdot \frac{T}{M_{AI}}$	45.0
	2	$R_{AI} = -0.00948 + 0.00582 \cdot T - 0.246 \cdot \frac{T}{M_{AI}}$	44.8
SH	1	$R_{SH} = 0.0278 - 0.0707 \cdot RH + 0.0554 \cdot \sqrt{RH} + 0.000283 \cdot M_{SH} - \ldots$ $\ldots - 0.0134 \cdot \ln(M_{SH}) + 0.000009 \cdot (T \cdot M_{SH})$	24.7
	2	$R_{SH} = 0.0203 - 0.0347 \cdot \sqrt{RH} + 0.000362 \cdot \frac{T}{\ln(M_{SH})}$	32.2
WH	1	$R_{WH} = -0.0116 + 0.0113 \cdot \sqrt{RH} + 0.000015 \cdot (T \cdot M_{WH})$	2.7
	2	$R_{WH} = 0.0215 - 0.000712 \cdot T - 0.00845 \cdot \sqrt{RH} - 0.000524 \cdot M_{WH} + \ldots$ $\ldots + 0.000024 \cdot (T \cdot M_{WH})$	2.6

Table 9.6 Linear regression equations developed for the UG and ES areas

Area	Model	Equation	R^2 (%)
UG	1	$R_{UG} = 0.0203 + 0.00299 \cdot T_{UG} - 0.392 \cdot \sqrt{RH_{UG}} - 0.000017 \cdot (T_{UG} \cdot M_{UG})$	17.4

	2	$R_{UG} = 0.107 + 0.00218 \cdot T_{UG} - 0.238 \cdot \sqrt{RH_{UG}} - 0.000010 \cdot (T_{UG} \cdot M_{UG})$	19.2
ES	1	$R_{ES} = 0.439 - 0.00848 \cdot T_{ES} - 0.207 \cdot \sqrt{RH_{ES}} - 0.0122 \cdot \frac{M_{ES}}{T_{ES}}$	7.4
	2	$R_{ES} = 0.387 - 0.00825 \cdot T_{ES} - 0.199 \cdot \sqrt{RH_{ES}} - 0.00826 \cdot \frac{M_{ES}}{T_{ES}}$	18.6

The adequacy of Models 1 and 2 is compared by looking at the coefficient of multiple determination R^2 and the normal probability plots of the residuals. As it was mentioned before, the coefficient of multiple determination is not a good estimator by itself, thus, the normal probability plot of the residuals was also analyzed. The output from MINITAB and the normal probability plots for the regression analysis is attached in Appendix C

Regression analysis results using data without the outliers (Model 2) were more satisfactory for each of the five areas of interest. The statement is based on the normal probability plot of the residuals, which have a better linear relationship (see Appendix C). This and the simplicity suggest the use of the regression equations developed for Model 2 as they seem to be the most adequate.

Moisture balance quantification using the regression equations developed for Models 1 and 2 are compared with moisture balance calculated using psychrometric relationships. This will give additional support to the decision of selecting the most adequate liner regression equations. The quantification of moisture balance is described in section 10.2 of the next Chapter.

Chapter 10

RESULTS

10.1 Comparison between actual climatic data and CLIMSIM results

Dry bulb temperature, relative humidity, barometric pressure and mass flow rate measurements from AI and SH shafts were picked at four different dates and times. The measurements picked from the actual climatic data and the resulting moisture content at these four points (computed using the subroutines developed in excel) were compared against results obtained using CLIMSIM. This software developed by MVS, Inc. is used for estimating variations in psychrometric and thermodynamic properties along underground openings or airways given airflow inlet conditions

Table 10.1 summarizes the input parameters and constants used in CLIMSIM for predicting the specific humidity at the outlet of both AI and SH shaft. Thermal difusivity is calculated using the following equation:

$$\alpha_r = \frac{k}{\rho_r \cdot C_r}$$

Where:

k = Thermal conductivity, W/m-K

ρ_r = Density, kg/m^3

C_r = Specific heat, J/kg

Table 10.1 Input constants for CLIMSIM

Constant/parameter	Symbol	AI Shaft	SH Shaft
Length, m	L	650	650
Depth in, m		0	0
Depth out, m		650	650
Area, m^2	A	29.22	8.68
Perimeter, m	P	19.18	10.45
Friction, kg/m^3	k	0.0050	0.016
Age in, days		5000	5000
Age out, days		5000	5000
Virgin Rock Temp, ^{O}C	VRT	19.0	19.0
Geothermal Step, m/^{O}C		71.7*	71.7
Conductivity, (W/m-^{O}C		5.0**	5.0
Diffusivity, m^2/s x 10^{-6}	α_r	2.675***	2.675
Interval, m		65	65

* Using 19^{O}C of temperature at a depth of 10-m and 28^{O}C virgin rock temperature at a depth of 655-m.
** Average value of salt rock.
*** Using salt density of 2,100 kg/m^3 and specific heat 890 J/kg.

The selected airflow inlet conditions (dry bulb temperature, relative humidity, surface barometric pressure) and airflow rate at each of the AI and SH shafts where used in the analysis with CLIMSIM. The results are summarized in Table.10.2

Table 10.2 Actual Climatic data and CLIMSIM* results

			Air Intake						Air Outlet					
Area	**Date**	**Time**	**Q**	**T_d**	**T_w**	**RH**	**BP**	**X**	**T_d**	**T_w**	**RH**	**BP**	**X**	**Wetness**
			(m^3/s)	**(°C)**	**(°C)**	**(%)**	**(Pa)**	**(g/kg)**	**(°C)**	**(°C)**	**(%)**	**(Pa)**	**(g/kg)**	**Factor**
Air Intake Shaft	9/17/99	10:00:00	97.05	18.87	15.70	73.63	89.82	11.30	25.77	19.10	53.89	96.59	11.70	
								11.26	*24.21*	*18.62*	*59.25*	*96.78*	*11.72*	*0.13*
	11/5/99	14:00:00	139.98	27.18	10.90	9.86	89.56	2.50	27.28	12.10	12.84	96.60	3.00	
								2.46	*31.74*	*13.98*	*10.16*	*96.33*	*3.09*	*0.05*
	3/25/00	10:00:00	143.56	18.00	15.80	80.62	89.36	11.80	22.19	17.50	63.68	96.27	11.20	
								11.81	*24.06*	*18.69*	*60.67*	*92.27*	*11.96*	*0.005*
	4/2/00	20:00:00	145.66	12.70	8.40	58.42	89.57	6.00	18.85	11.20	38.84	96.68	5.50	
								5.97	*18.85*	*11.87*	*42.57*	*96.65*	*6.09*	*0.03*
Salt Hanling Shaft (SH)	9/17/99	10:00:00	22.65	18.87	15.70	73.63	89.82	11.30	26.94	19.20	48.83	96.36	11.40	
								11.26	*24.79*	*18.70*	*56.54*	*96.72*	*11.58*	*0.03*
	11/5/99	14:00:00	53.49	27.18	10.90	9.86	89.56	2.50	25.12	11.40	15.26	96.44	3.20	
								2.46	*30.52*	*13.85*	*12.24*	*95.97*	*3.49*	*0.03*
	3/25/00	10:00:00	37.91	18.00	15.80	80.62	89.36	11.80	21.98	16.70	59.64	96.07	10.40	
								11.81	*24.05*	*18.75*	*61.11*	*96.11*	*12.06*	*0.03*
	4/2/00	20:00:00	49.61	12.70	8.40	58.42	89.57	6.00	19.90	11.50	35.89	96.46	5.40	
								5.97	*18.97*	*12.03*	*44.13*	*96.33*	*6.31*	*0.03*

* *Italics* indicate results using CLIMSIM

CLIMSIM was executed using an arbitrary shaft wall wetness-factor. The wetness factor was adjusted by trial and error until the specific humidity (X, g/kg) calculated using the software had a value close to the actual specific humidity at the airway outlet. The actual specific humidity is calculated using temperature relative humidity and barometric pressure measurements). The wetness factor is defined as the fraction of the rock surface that is partially wet. From Table 10.2 we can conclude that in order to obtain similar specific humidities values, the wall wetness factor has to be considerably smaller for the SH shaft. Walls at SH shaft are dryer than the walls at the AI shaft.

Actual climatic data and results using CLIMSIM have some discrepancy. The following reasons for this discrepancy can be enumerated

1. CLIMSIM does not take into account the moisture absorption of salt. The absorption takes place in the lower, unlined section of the shafts.

2. CLIMSIM assumes the past constant barometric conditions at the shaft intake. In reality, these conditions vary widely at the WIPP site.

3. CLIMSIM assumes that the wetness factor is constant along the entire length of the airway. In reality, it may be much higher close to the air intake due to water seepage through the wall lining and possible water condensation during previous periods.

Most likely, CLIMSIM would give better results if the shafts could be divided into several sections to account for the lined and unlined sections of the shafts.

10.2 Moisture balance quantification

Moisture balance quantification was accomplished by using actual or measured data (R_{Meas}) and the regression equations from Table 10.3.and Table 10.4. Nomenclature is as follows:

1. R_{Meas} = moisture balance calculation using actual or measured data

2. R_{Mod-1} = moisture balance calculation using the regression equation for Model 1

3. R_{Mod-2} = moisture balance calculation using the regression equation for Model 2

At the Air Intake Shaft; an average annual rate of evaporation of 0.0723 l/s (1.145gpm) was computed using the actual data. The values obtained using the regression equations for Models 1 and 2 are 0.0784 l/s and 0.0705 l/s (1.242gpm and 1.117gpm respectively). The relative errors (**e**) in the calculation using the regression equations are 8.4 % and 2.5 % respectively.

The uncertainties in the calculations using the regression equations are reasonably acceptable for the case of the AI shaft. On the contrary, the uncertainties for the other areas are not as good as for this area. The results for the other four areas are summarized on Table 10.3 and Table 10.4. (Table 10.5 a summary for AI, SH, and UG in gallons)

Table 10.3 Monthly average moisture balance for AI and SH areas

Month	$R_{AI-Meas}$ (l/s)	$R_{AI-Mod-1}$ (l/s)	$R_{AI-Mod-2}$ (l/s)	$R_{SH-Meas}$ (l/s)	$R_{SH-Mod-1}$ (l/s)	$R_{SH-Mod-2}$ (l/s)
Aug-99	0.1260	0.1251	0.1093	0.0057	0.0049	0.0017

Sep-99	0.0832	0.0924	0.0840	-0.0001	-0.0005	-0.0030
Oct-99	0.0600	0.0767	0.0666	0.0012	0.0029	0.0004
Nov-99	0.0442	0.0589	0.0534	-0.0021	0.0012	-0.0003
Dec-99	0.0285	0.0329	0.0272	0.0005	-0.0006	-0.0007
Jan-00	0.0374	0.0332	0.0296	0.0024	0.0012	0.0001
Feb-00	0.0417	0.0478	0.0452	0.0026	0.0025	0.0021
Mar-00	0.0393	0.0605	0.0531	0.0005	0.0027	0.0010
Apr-00	0.0575	0.0778	0.0736	0.0017	0.0042	0.0032
May-00	0.0894	0.1020	0.0951	0.0023	0.0059	0.0047
Jun-00	0.1064	0.1053	0.0957	-0.0011	-0.0009	-0.0030
Jul-00	0.1536	0.1277	0.1127	0.0071	0.0056	0.0019
Annual Avg.	0.0723	0.0784	0.0705	0.0017	0.0024	0.0007
Summary in m³						
m³/d	6.24	6.77	6.09	0.15	0.21	0.06
m³/mo	187.31	203.09	182.65	4.44	6.32	1.72
m³/yr	2,278.90	2,470.88	2,222.25	54.04	76.88	20.98
e%		8.4%	2.5%		42.3%	61.2%

Table 10.4 Monthly average moisture balance for WH, UG and ES areas

	$R_{WH-Meas}$	$R_{WH-Mod-1}$	$R_{WH-Mod-2}$	$R_{UG-Meas.}$	$R_{UG-Mod-1}$	$R_{UG-Mod-2}$	$R_{ES-Meas.}$	$R_{ES-Mod-1}$	$R_{ES-Mod-2}$
Month	**(l/s)**	**(l/s)**	**(l/s)**	**(l/s)**	**(l/s)**	**(l/s)**	**(l/s)**	**(l/s)**	**(l/s)**
Aug-99	0.0416	0.0119	0.0021	-0.0244	-0.0477	-0.0286	-0.0660	-0.0326	-0.0447
Sep-99	0.0315	0.0079	-0.0002	-0.0371	-0.0734	-0.0439	-0.0504	-0.0286	-0.0391
Oct-99	0.0008	0.0055	-0.0001	-0.0117	-0.0294	-0.0212	-0.0180	0.0042	-0.0042
Nov-99	-0.0032	0.0032	-0.0003	-0.0269	-0.0340	-0.0240	-0.0085	0.0109	0.0050
Dec-99	0.0004	0.0002	-0.0016	-0.0198	-0.0111	-0.0151	0.0065	0.0331	0.0284
Jan-00	-0.0003	-0.0009	0.0009	-0.0245	-0.0046	-0.0172	0.0314	0.0295	0.0291
Feb-00	-0.0017	0.0025	-0.0010	-0.0035	-0.0070	-0.0120	0.0353	0.0276	0.0258
Mar-00	-0.0042	0.0014	0.0015	-0.0276	-0.0134	-0.0150	0.0038	0.0257	0.0191
Apr-00	-0.0001	0.0025	0.0015	-0.0150	-0.0102	-0.0097	0.0250	0.0186	0.0113
May-00	0.0076	0.0092	0.0019	-0.0306	-0.0237	-0.0074	0.0601	-0.0024	-0.0123
Jun-00	-0.0058	0.0086	-0.0002	-0.0545	-0.0872	-0.0475	0.0670	-0.0346	-0.0460
Jul-00	-0.0004	0.0084	0.0008	-0.0795	-0.0471	-0.0293	-0.0281	-0.0298	-0.0411
Annual Avg.	0.0055	0.0050	0.0004	-0.0296	-0.0324	-0.0226	0.0048	0.0018	-0.0057
Summary in m³									
m³/d	0.48	0.44	0.04	-2.56	-2.80	-1.95	0.42	0.16	-0.49
m³/mo	14.27	13.09	1.12	-76.72	-83.98	-58.54	12.54	4.68	-14.81
m³/yr	173.57	159.21	16.66	-933.43	-1,021.72	-712.19	152.61	56.97	-180.16
e%		8.3%	92.1%		9.5%	23.7%		62.7%	218.1%

Table 10.5 Average moisture balance (in gallons) for AI SH and UG areas

	$R_{AI-Meas.}$	$R_{AI-Mod-1}$	$R_{AI-Mod-2}$	$R_{SH-Meas.}$	$R_{SH-Mod-1}$	$R_{SH-Mod-2}$	$R_{UG-Meas.}$	$R_{UG-Mod-1}$	$R_{UG-Mod-2}$
g.p.m.	1.145	1.242	1.117	0.027	0.039	0.011	-0.469	-0.514	-0.358
g.p.d.	1,649.3	1,788.3	1,608.4	39.1	55.6	15.2	-675.6	-739.5	-515.5

g.p.mo	49,481.3	53,649.6	48,251.3	1,173.4	1,669.2	455.6	-20267.4	-22184.5	-15463.6
g.p.y.	602,022.0	652,736.9	587,056.9	14,276.9	20,309.1	5,543.5	-246587.2	-269911.2	-188140.9

10.3 Linear regression equations

Estimating moisture balance in ventilation air at the WIPP underground facility, using regression equations were possible for three areas AI, SH shafts and UG workings. The suggested equations are:

- AI shaft area:

$$R_{AI} = -0.00948 + 0.00582 \cdot T - 0.246 \cdot \frac{T}{M_{AI}} \tag{10.1}$$

$R^2 = 44.8\%$

- SH shaft area:

$$R_{SH} = 0.0203 - 0.0347 \cdot \sqrt{RH} + 0.000362 \cdot \frac{T}{\ln(M_{SH})} \tag{10.2}$$

$R^2 = 32.2\%$

- UG workings:

$$R_{UG} = 0.107 + 0.00218 \cdot T_{UG} - 0.238 \cdot \sqrt{RH_{UG}} - 0.000010 \cdot (T_{UG} \cdot M_{UG})$$

(10.3)

$R^2 = 19.2\%$

Figure 10.2 is graphical summary of the average monthly moisture balance for these three areas obtained with the suggested regression equations and moisture balance results using measured values.

The three regression equations were suggested after observing the results of moisture balance quantification (summarized on Table 10.4 and Table 10.5), normal probability plots of the residuals and the coefficient of multiple determination R^2.

Regression analysis for the other two areas WH and ES shafts, are not sufficiently supported. Discrepancies between the results of moisture balance calculated using measured parameters and the results using the regression equations for these areas is considerably large.

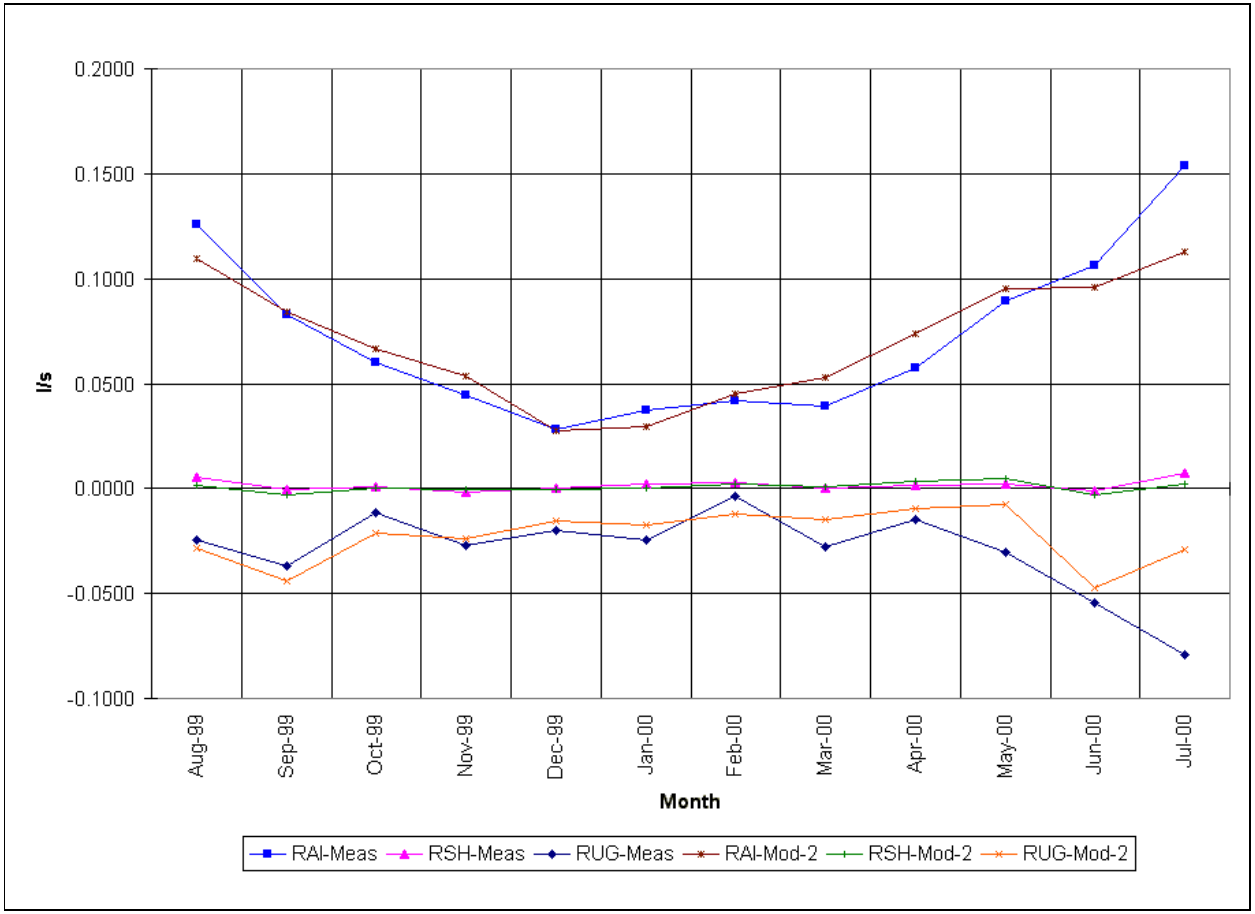

Figure 10.2 Average monthly moisture balance for AI, SH and UG areas.

Chapter 11

CONCLUSIONS

Quantifying the amount of moisture given off or picked up in air ventilation at the WIPP underground facility using regression equations was possible for the three areas. They are:

1. AI shaft area
2. SH shaft area
3. UG workings

Air intake conditions used as independent variables are temperature, relative humidity and mass flow rate. The influence of barometric pressure was insignificant in the regression analysis. From the results described in Chapter 10, we can conclude the following:

11.1 AI shaft area

Evaporation is occurring at this area. The calculated amount of water evaporation, using the suggested regression equation is (equation 10.1) is 2,222.25 ± 44.45 m^3/year. Most of the evaporation is occurring during the summer time. See Figure 11.1. Air inlet temperature has a major influence onto the moisture balance at this particular shaft. Moisture evaporation in air will increase as the temperature raises. Raising temperature will evaporate water from the shaft walls as the air moves from the inlet to the shaft outlet. The amount of evaporation at this shaft also indicates that this shaft is wet most of the time of the year.

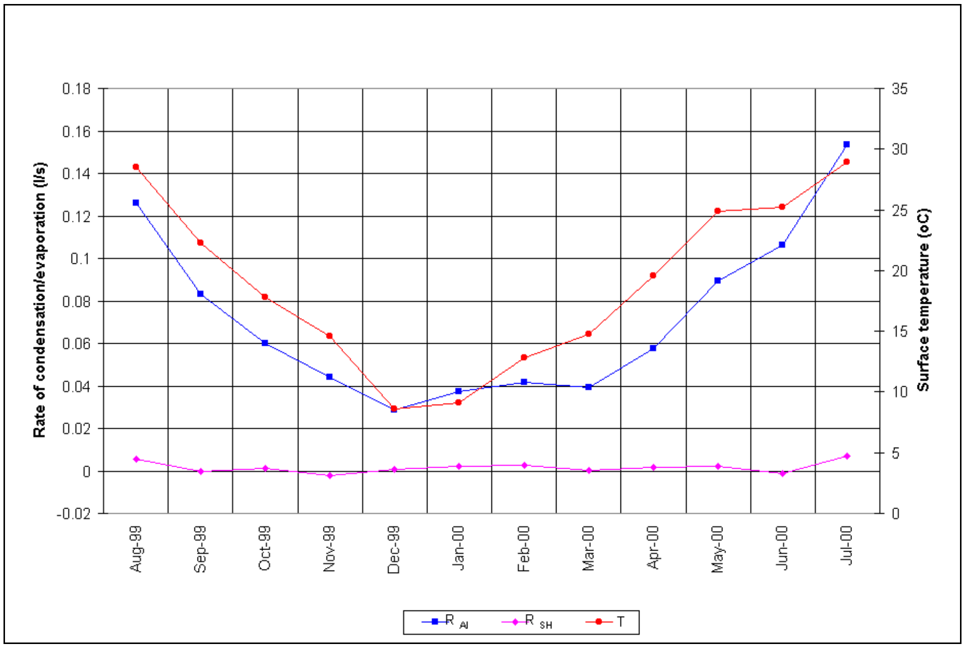

Figure 11.1 Surface temperature onto moisture balance at AI and SH shafts

11.2 SH shaft area

The amount of water evaporation occurring at this particular area, is minor compared to the amount of evaporation occurring at the AI shaft area. Average water evaporation was found 20.98 m^3/year. This value was calculated using the model developed for this area (equation 10.2). The SH shaft is dry most of the time of the year. The shaft is most of the time dry. The air relative humidity at the inlet of this shaft has most of the influence onto the moisture balance at this particular area.

11.3 Underground Workings

About 40% of the water evaporated at the AI and SH Shaft area is being condensed or absorbed in the Underground Workings. Absorption will occur in freshly exposed rock or on the walls without lining, where salt rock can absorb the moisture due to its high absorption and storage capabilities. The absorption of moisture by the salt rock at the UG workings depends mostly on the moisture content of the flowing air. The amount of water being absorbed in the Underground Workings is 712.19 m^3/year. This value was obtained using equation 10.3.

The uncertainty in the results for the SH shaft and the UG workings is large (± 61.2% and ± 23.7% respectively). Despite of these large uncertainties, the equations are useful to estimate and provide guidelines about the processes involved with moisture balance, if nothing else is available.

Chapter 12

RECOMMENDATIONS FOR FUTURE WORK

From the results summarized in Chapter 10 and the conclusions in chapter 11 we can suggest the following recommendations:

1. Although equations 10.1, 10.2 and 10.3 suggested in Chapter 10 where proved to work for an approximate estimation of moisture balance at the AI, SH shafts and the UG workings at the WIPP facility, they need further investigation and testing.

2. These equations can be implemented for monitoring moisture balance at the mentioned areas using real time data. Certainly, the results would be estimations of the process. A continuous graphical display of the information would be beneficial for detecting malfunctioning of the sensors or unusual events in the ventilation system by displaying picks or valleys during the daily process of moisture balance. Process that is taking place underground because of the airflow in the ventilation system.

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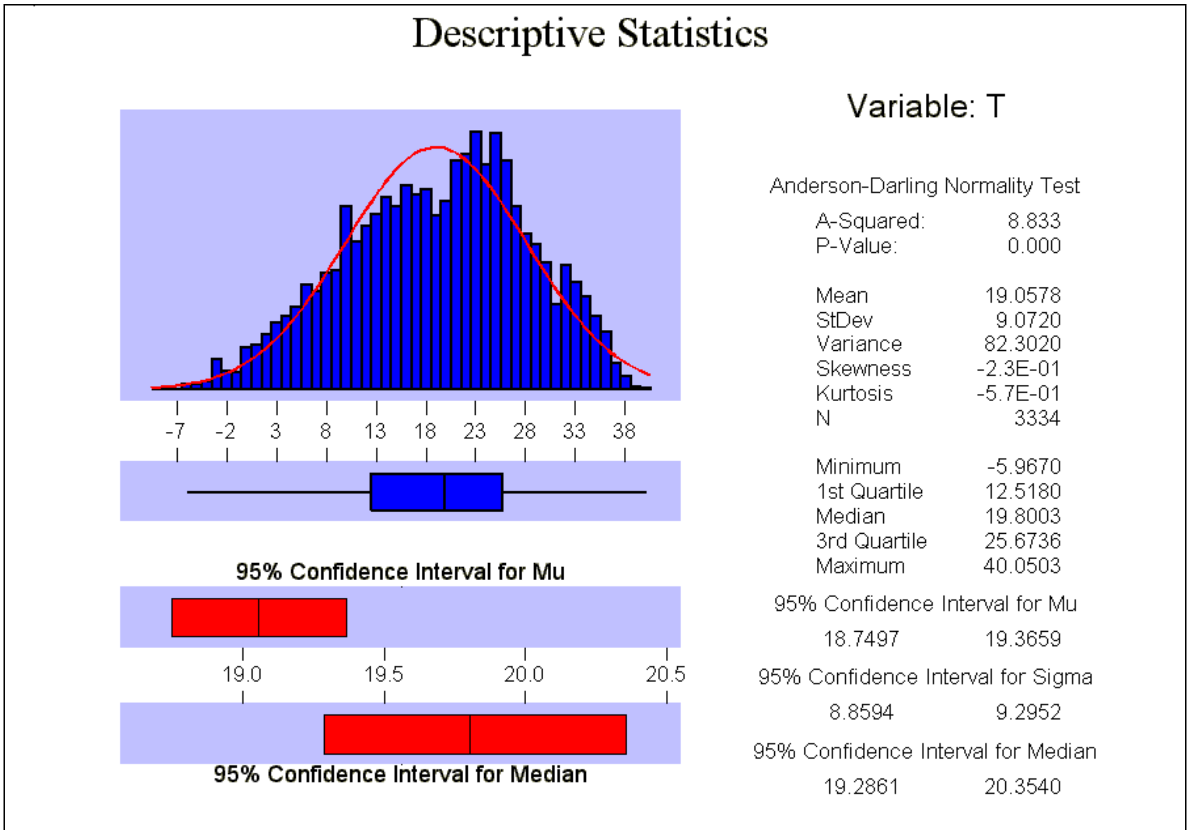
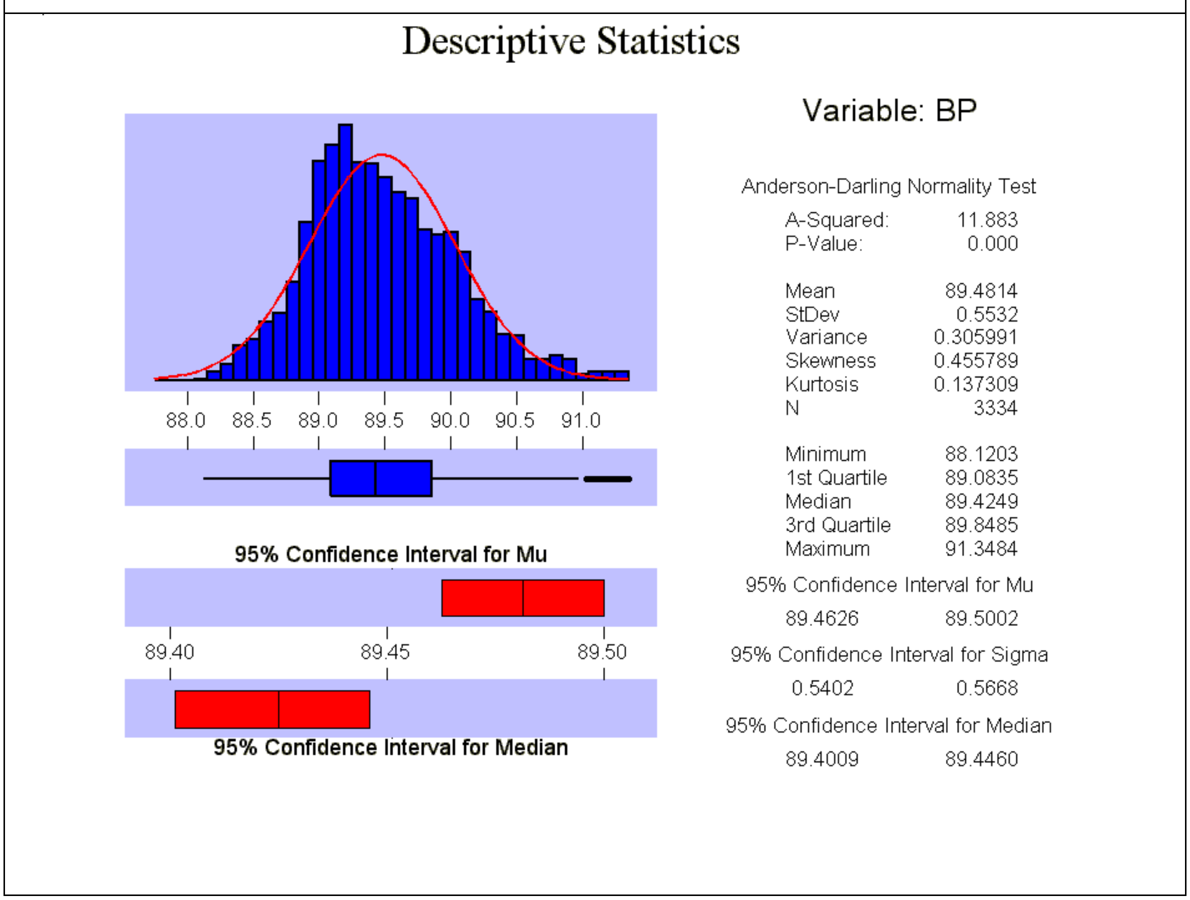
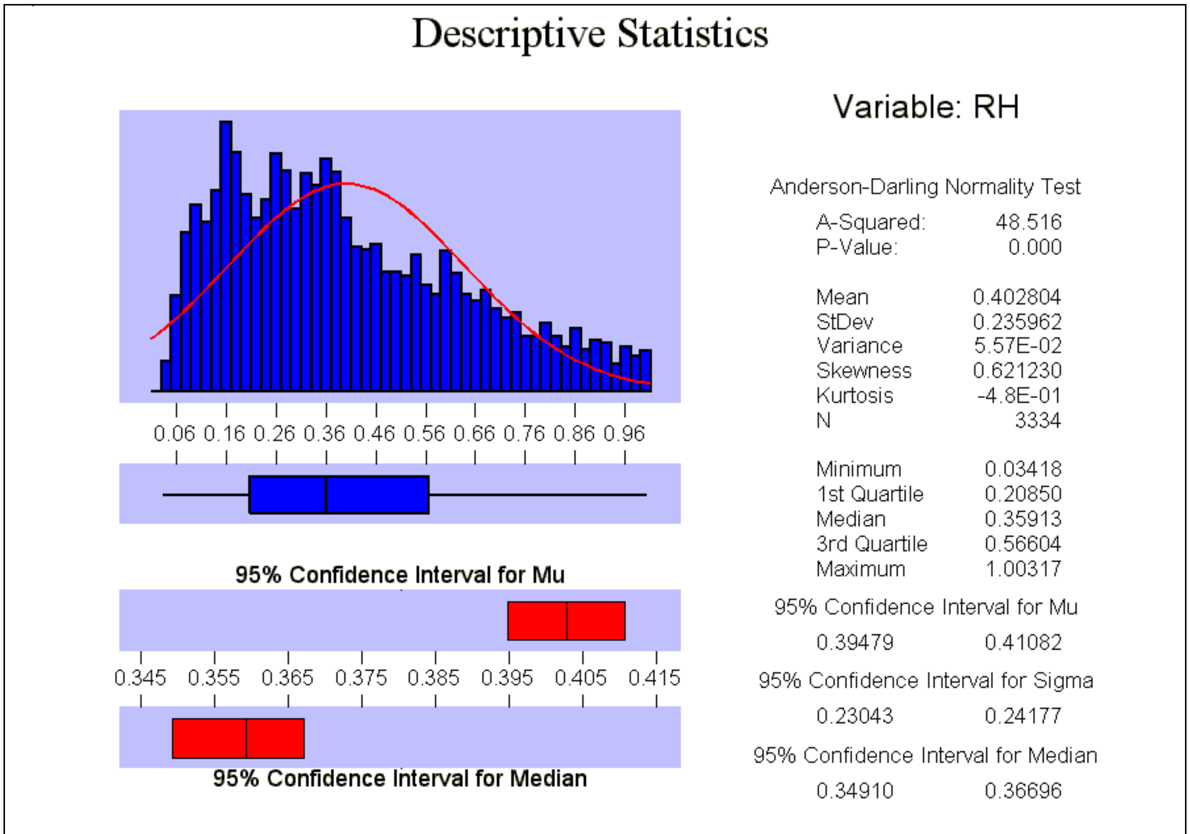
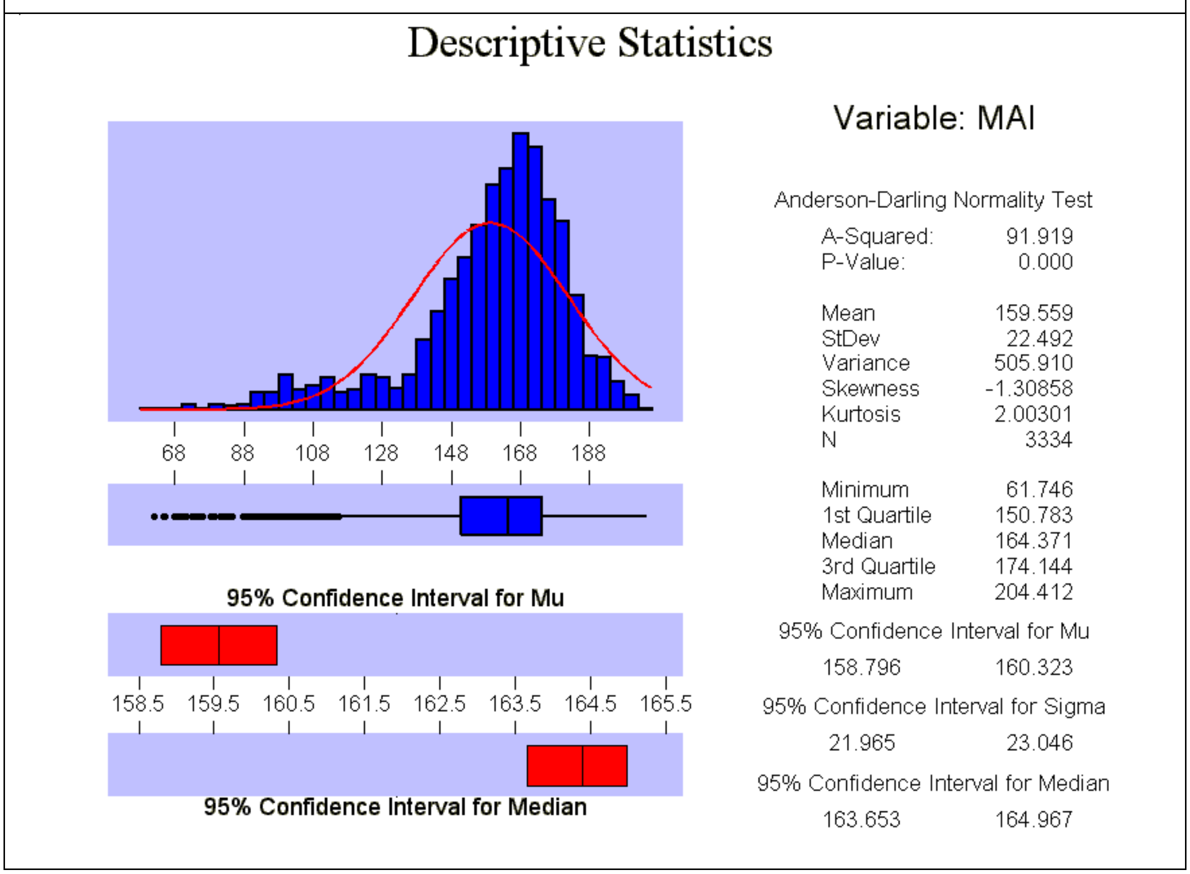
APPENDIX A

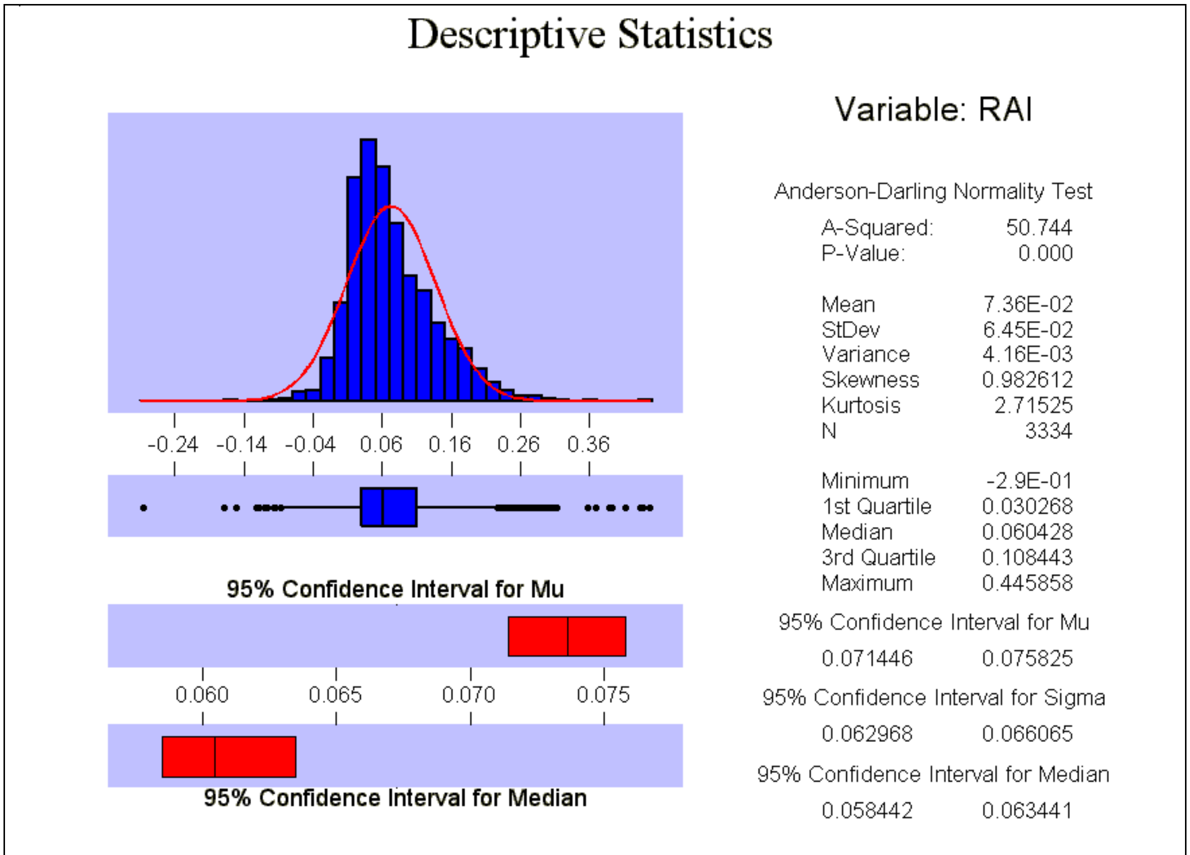
SUMMARY STATISTICS OF VARIABLES USED IN THE REGRESSION ANALYSIS

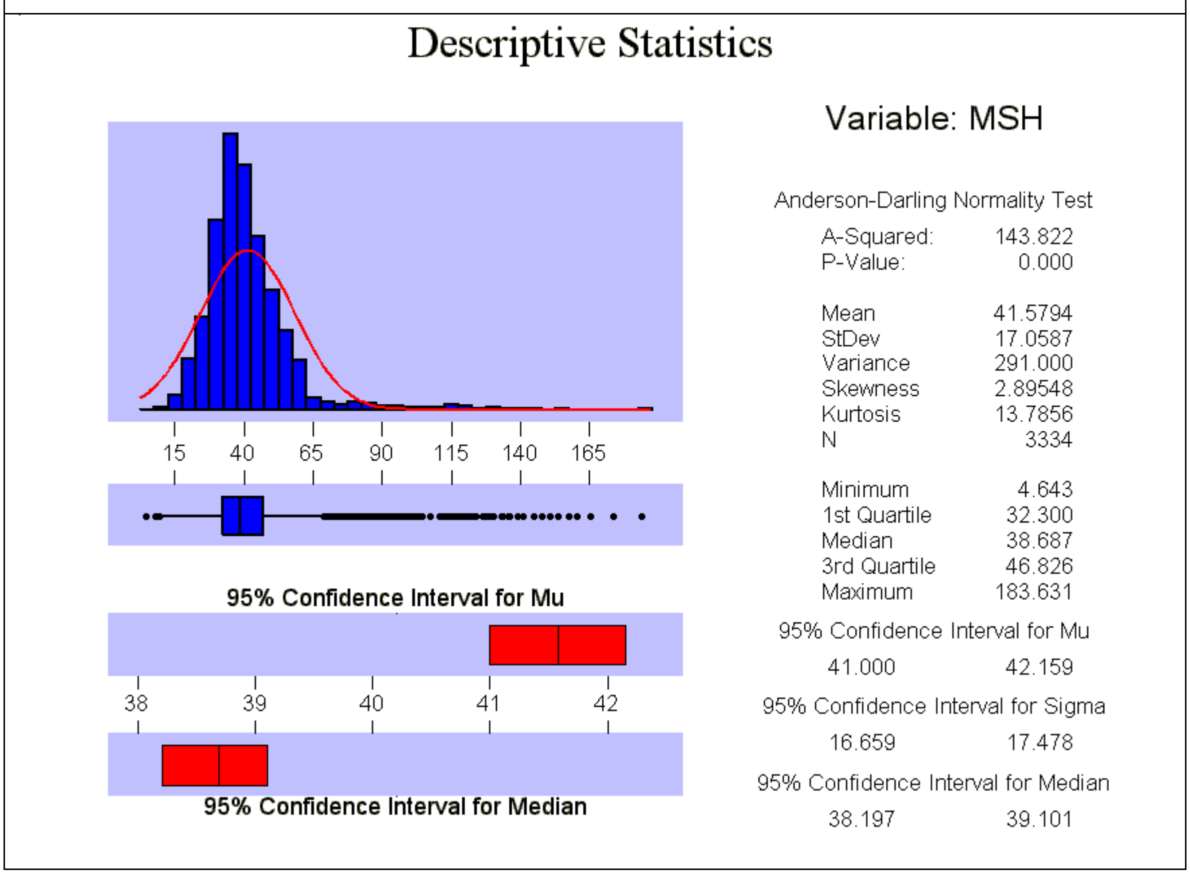

Descriptive Statistics
Variable: T
Anderson-Darling Normality Test
A-Squared: 8.833
P-Value: 0.000
Mean 19.0578
StDev 9.0720
Variance 82.3020
Skewness -2.3E-01
Kurtosis -5.7E-01
N 3334
Minimum -5.9670
1st Quartile 12.5180
Median 19.8003
3rd Quartile 25.6736
Maximum 40.0503
95% Confidence Interval for Mu
18.7497 19.3659
95% Confidence Interval for Sigma
8.8594 9.2952
95% Confidence Interval for Median
19.2861 20.3540
-7 -2 3 8 13 18 23 28 33 38
95% Confidence Interval for Mu
19.0 19.5 20.0 20.5
95% Confidence Interval for Median

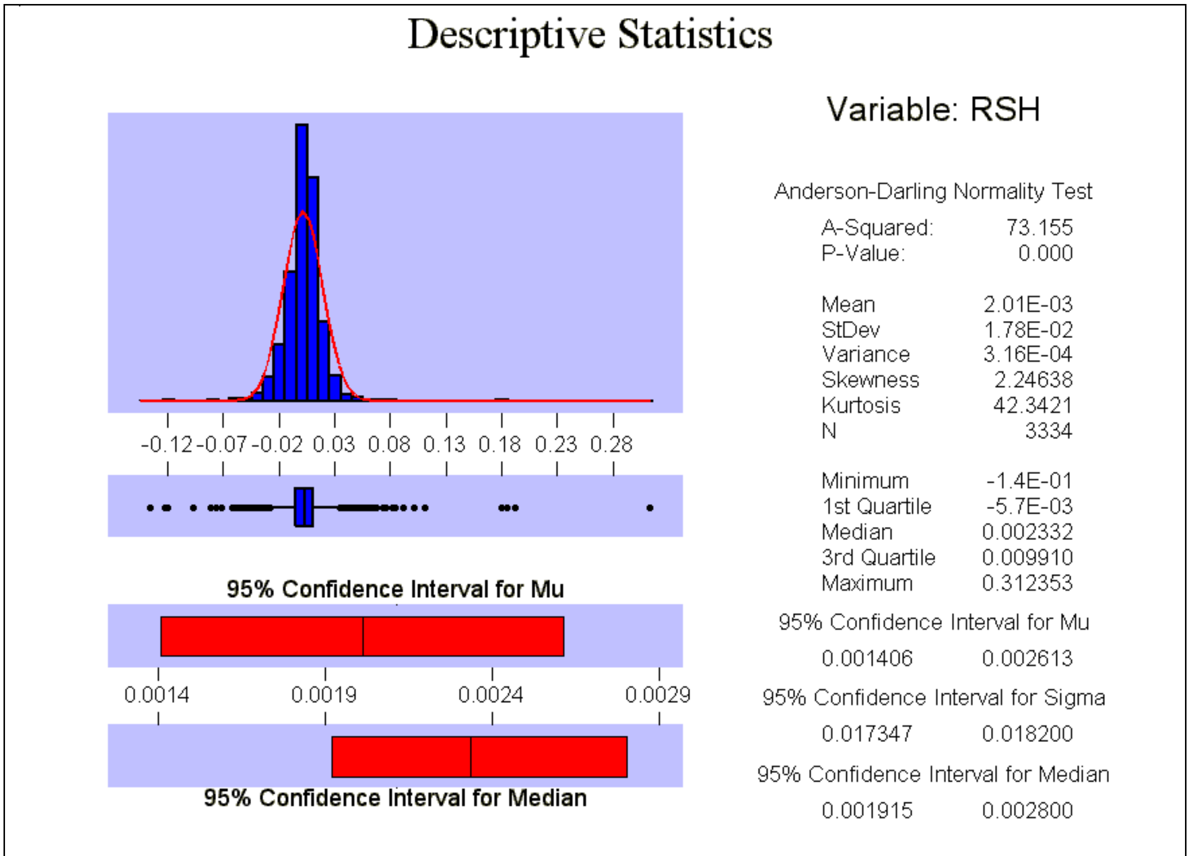

Descriptive Statistics
Variable: BP
Anderson-Darling Normality Test
A-Squared: 11.883
P-Value: 0.000
Mean 89.4814
StDev 0.5532
Variance 0.305991
Skewness 0.455789
Kurtosis 0.137309
N 3334
Minimum 88.1203
1st Quartile 89.0835
Median 89.4249
3rd Quartile 89.8485
Maximum 91.3484
95% Confidence Interval for Mu
89.4626 89.5002
95% Confidence Interval for Sigma
0.5402 0.5668
95% Confidence Interval for Median
89.4009 89.4460
88.0 88.5 89.0 89.5 90.0 90.5 91.0
95% Confidence Interval for Mu
89.40 89.45 89.50
95% Confidence Interval for Median

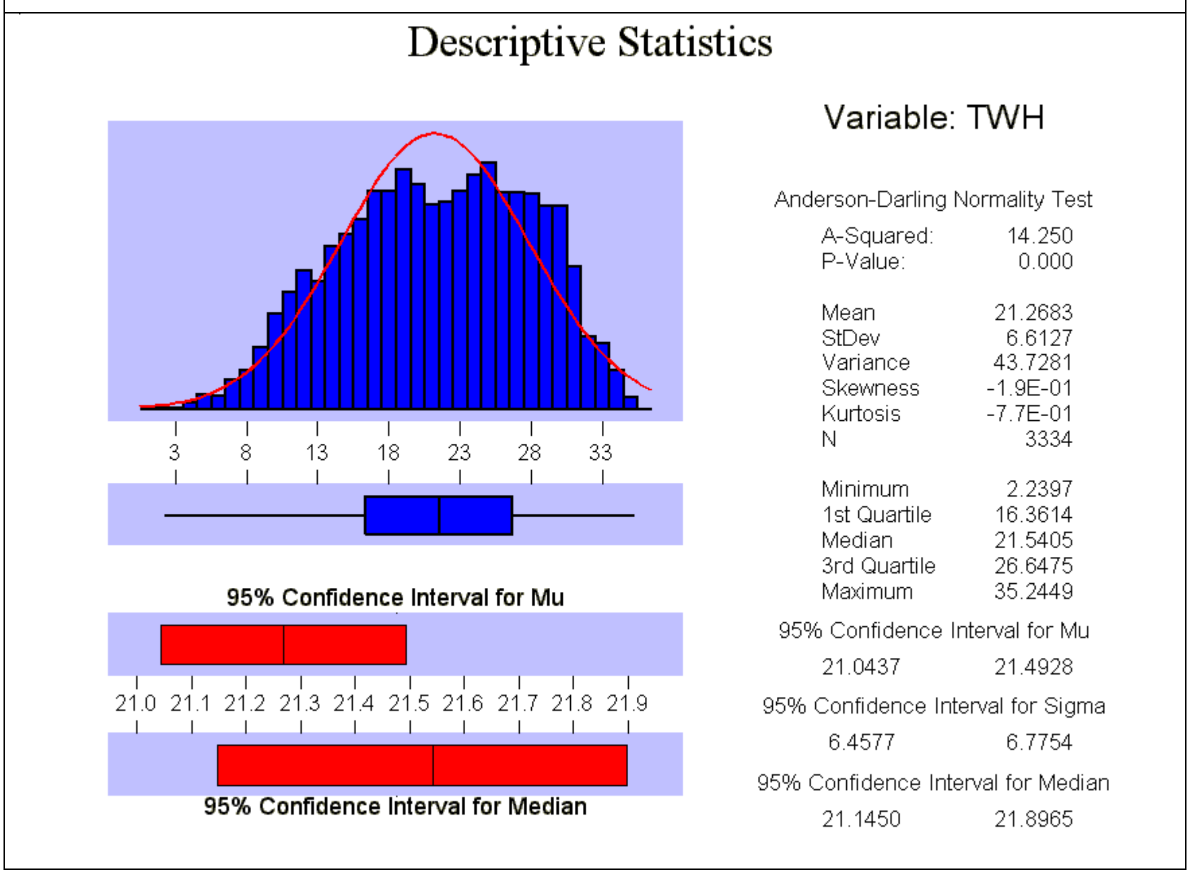

Descriptive Statistics
Variable: RH
0.06 0.16 0.26 0.36 0.46 0.56 0.66 0.76 0.86 0.96
95% Confidence Interval for Mu
0.345 0.355 0.365 0.375 0.385 0.395 0.405 0.415
95% Confidence Interval for Median
Anderson-Darling Normality Test
A-Squared: 48.516
P-Value: 0.000
Mean 0.402804
StDev 0.235962
Variance 5.57E-02
Skewness 0.621230
Kurtosis -4.8E-01
N 3334
Minimum 0.03418
1st Quartile 0.20850
Median 0.35913
3rd Quartile 0.56604
Maximum 1.00317
95% Confidence Interval for Mu
0.39479 0.41082
95% Confidence Interval for Sigma
0.23043 0.24177
95% Confidence Interval for Median
0.34910 0.36696


Descriptive Statistics
Variable: MAI
68 88 108 128 148 168 188
95% Confidence Interval for Mu
158.5 159.5 160.5 161.5 162.5 163.5 164.5 165.5
95% Confidence Interval for Median
Anderson-Darling Normality Test
A-Squared: 91.919
P-Value: 0.000
Mean 159.559
StDev 22.492
Variance 505.910
Skewness -1.30858
Kurtosis 2.00301
N 3334
Minimum 61.746
1st Quartile 150.783
Median 164.371
3rd Quartile 174.144
Maximum 204.412
95% Confidence Interval for Mu
158.796 160.323
95% Confidence Interval for Sigma
21.965 23.046
95% Confidence Interval for Median
163.653 164.967

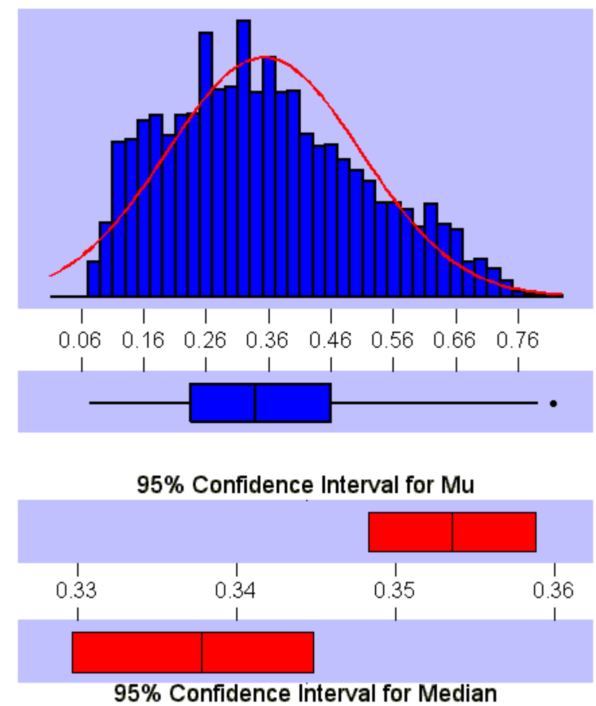

Descriptive Statistics
Variable: RAI
-0.24 -0.14 -0.04 0.06 0.16 0.26 0.36
95% Confidence Interval for Mu
0.060 0.065 0.070 0.075
95% Confidence Interval for Median
Anderson-Darling Normality Test
A-Squared: 50.744
P-Value: 0.000
Mean 7.36E-02
StDev 6.45E-02
Variance 4.16E-03
Skewness 0.982612
Kurtosis 2.71525
N 3334
Minimum -2.9E-01
1st Quartile 0.030268
Median 0.060428
3rd Quartile 0.108443
Maximum 0.445858
95% Confidence Interval for Mu
0.071446 0.075825
95% Confidence Interval for Sigma
0.062968 0.066065
95% Confidence Interval for Median
0.058442 0.063441


Descriptive Statistics
Variable: MSH
15 40 65 90 115 140 165
95% Confidence Interval for Mu
38 39 40 41 42
95% Confidence Interval for Median
Anderson-Darling Normality Test
A-Squared: 143.822
P-Value: 0.000
Mean 41.5794
StDev 17.0587
Variance 291.000
Skewness 2.89548
Kurtosis 13.7856
N 3334
Minimum 4.643
1st Quartile 32.300
Median 38.687
3rd Quartile 46.826
Maximum 183.631
95% Confidence Interval for Mu
41.000 42.159
95% Confidence Interval for Sigma
16.659 17.478
95% Confidence Interval for Median
38.197 39.101


Descriptive Statistics
Variable: RSH
-0.12 -0.07 -0.02 0.03 0.08 0.13 0.18 0.23 0.28
95% Confidence Interval for Mu
0.0014 0.0019 0.0024 0.0029
95% Confidence Interval for Median
Anderson-Darling Normality Test
A-Squared: 73.155
P-Value: 0.000
Mean 2.01E-03
StDev 1.78E-02
Variance 3.16E-04
Skewness 2.24638
Kurtosis 42.3421
N 3334
Minimum -1.4E-01
1st Quartile -5.7E-03
Median 0.002332
3rd Quartile 0.009910
Maximum 0.312353
95% Confidence Interval for Mu
0.001406 0.002613
95% Confidence Interval for Sigma
0.017347 0.018200
95% Confidence Interval for Median
0.001915 0.002800


Descriptive Statistics
Variable: TWH
3 8 13 18 23 28 33
95% Confidence Interval for Mu
21.0 21.1 21.2 21.3 21.4 21.5 21.6 21.7 21.8 21.9
95% Confidence Interval for Median
Anderson-Darling Normality Test
A-Squared: 14.250
P-Value: 0.000
Mean 21.2683
StDev 6.6127
Variance 43.7281
Skewness -1.9E-01
Kurtosis -7.7E-01
N 3334
Minimum 2.2397
1st Quartile 16.3614
Median 21.5405
3rd Quartile 26.6475
Maximum 35.2449
95% Confidence Interval for Mu
21.0437 21.4928
95% Confidence Interval for Sigma
6.4577 6.7754
95% Confidence Interval for Median
21.1450 21.8965

Descriptive Statistics



Variable: RHWH

Anderson-Darling Normality Test

A-Squared:	19.613
P-Value:	0.000
Mean	0.353580
StDev	0.155322
Variance	2.41E-02
Skewness	0.409168
Kurtosis	-5.5E-01
N	3334
Minimum	0.072998
1st Quartile	0.235107
Median	0.337769
3rd Quartile	0.459717
Maximum	0.815674

95% Confidence Interval for Mu

0.348306 0.358855

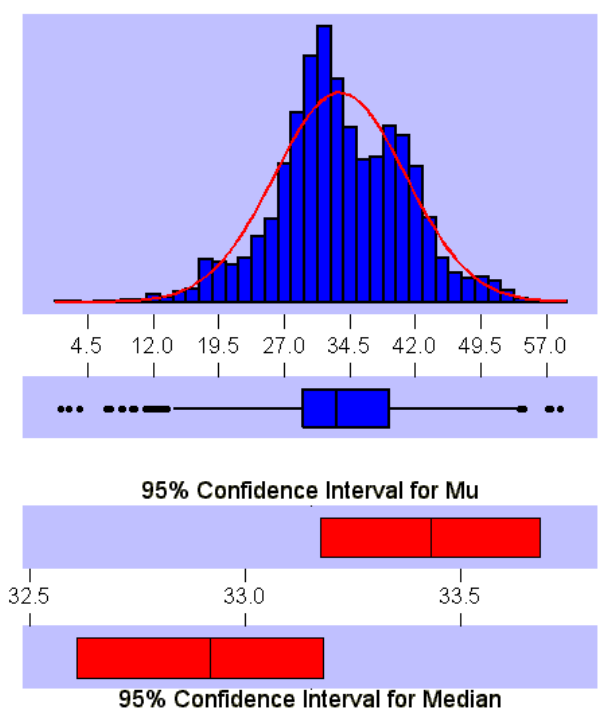
95% Confidence Interval for Sigma

0.151681 0.159143

95% Confidence Interval for Median

0.329570 0.344747

Descriptive Statistics



Variable: MWH

Anderson-Darling Normality Test

A-Squared:	6.845
P-Value:	0.000
Mean	33.4302
StDev	7.4910
Variance	56.1154
Skewness	-1.5E-01
Kurtosis	0.451122
N	3334
Minimum	1.4412
1st Quartile	29.0717
Median	32.9169
3rd Quartile	38.9246
Maximum	58.4543

95% Confidence Interval for Mu

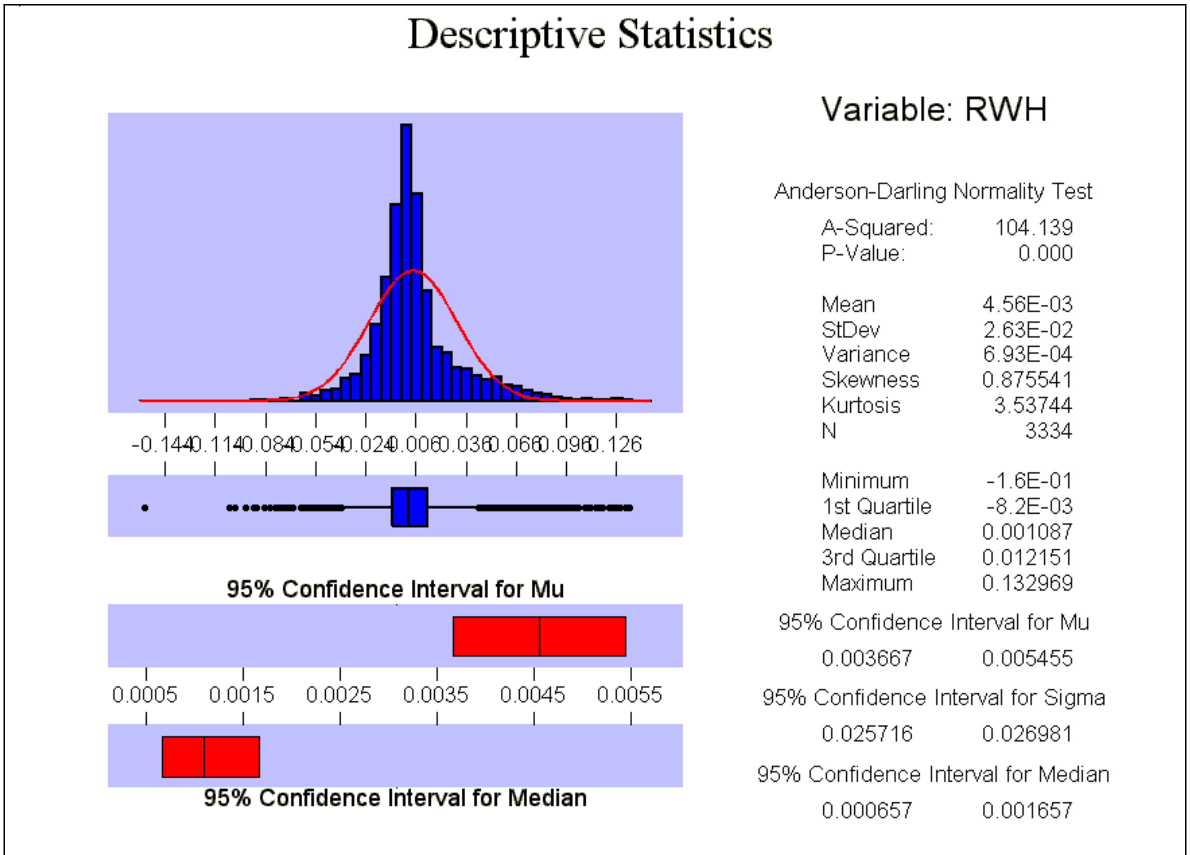
33.1758 33.6846

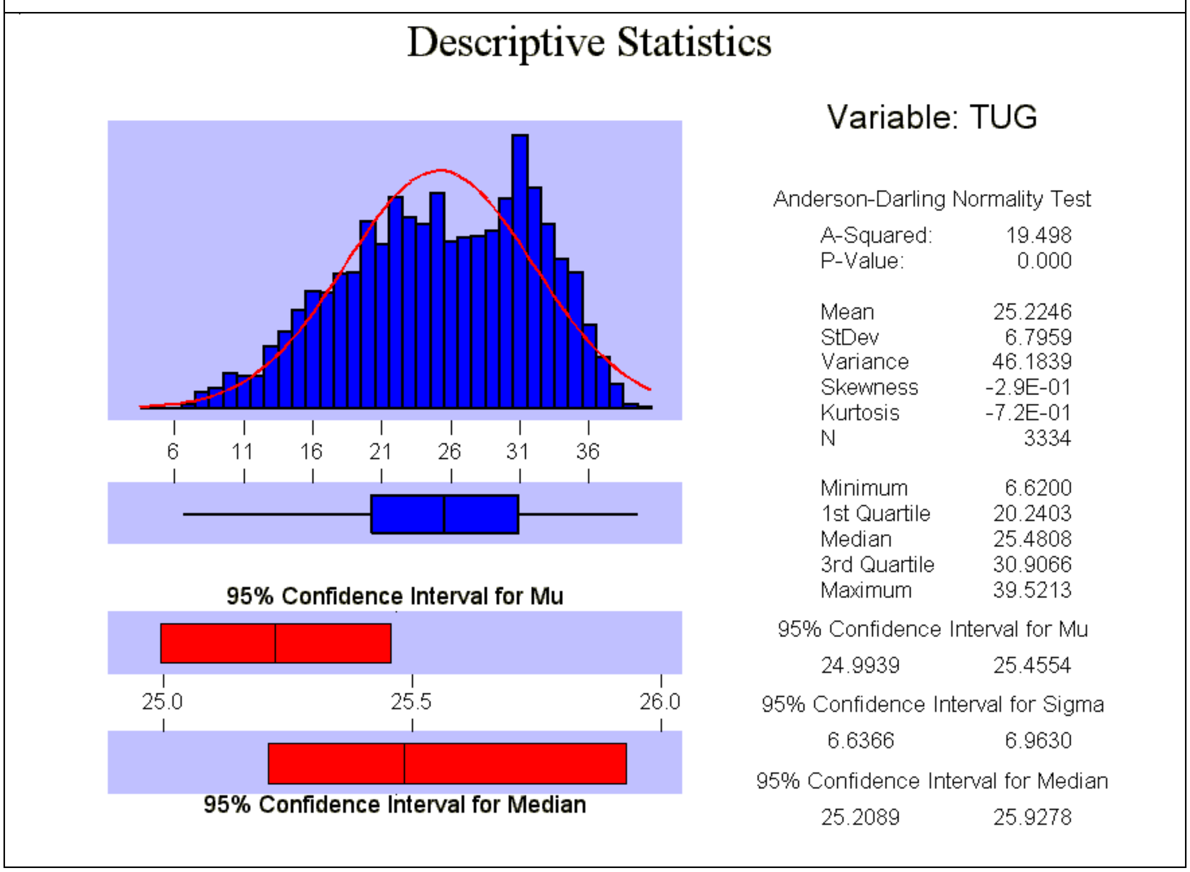
95% Confidence Interval for Sigma

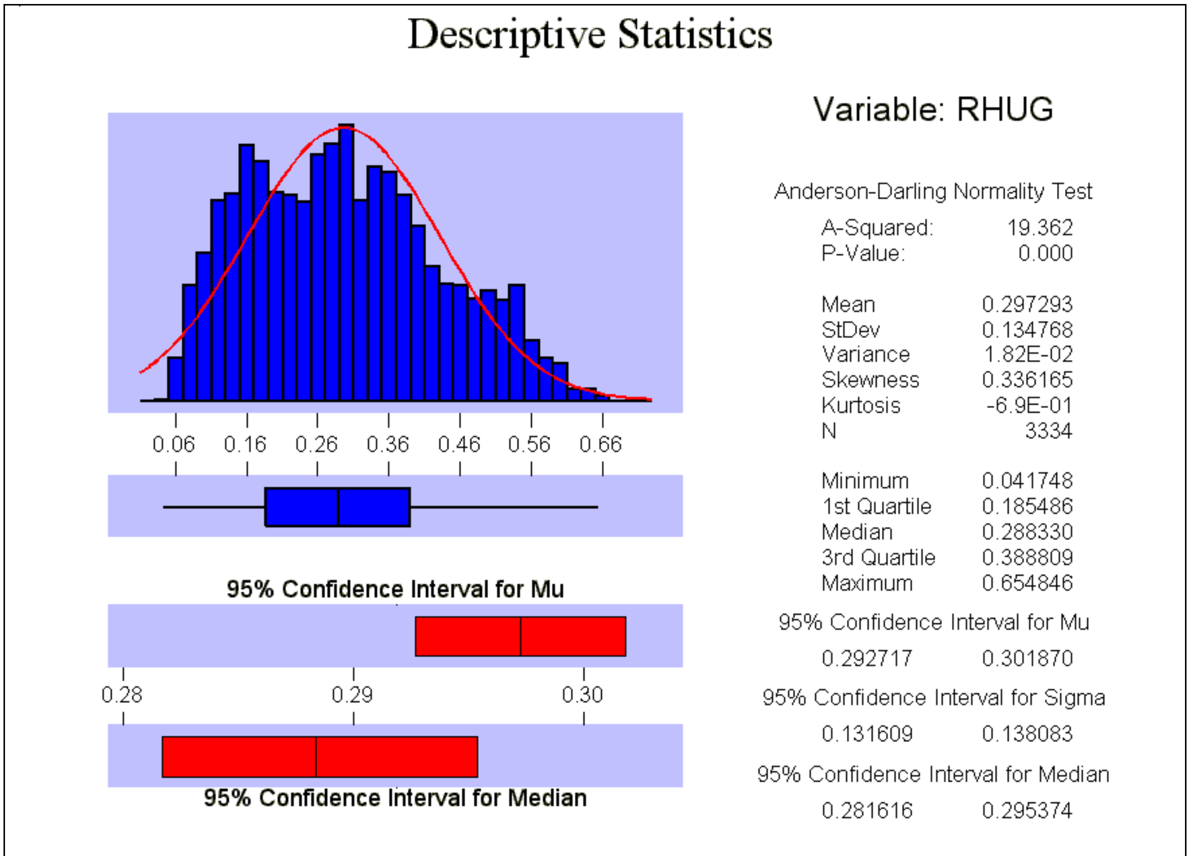
7.3154 7.6753

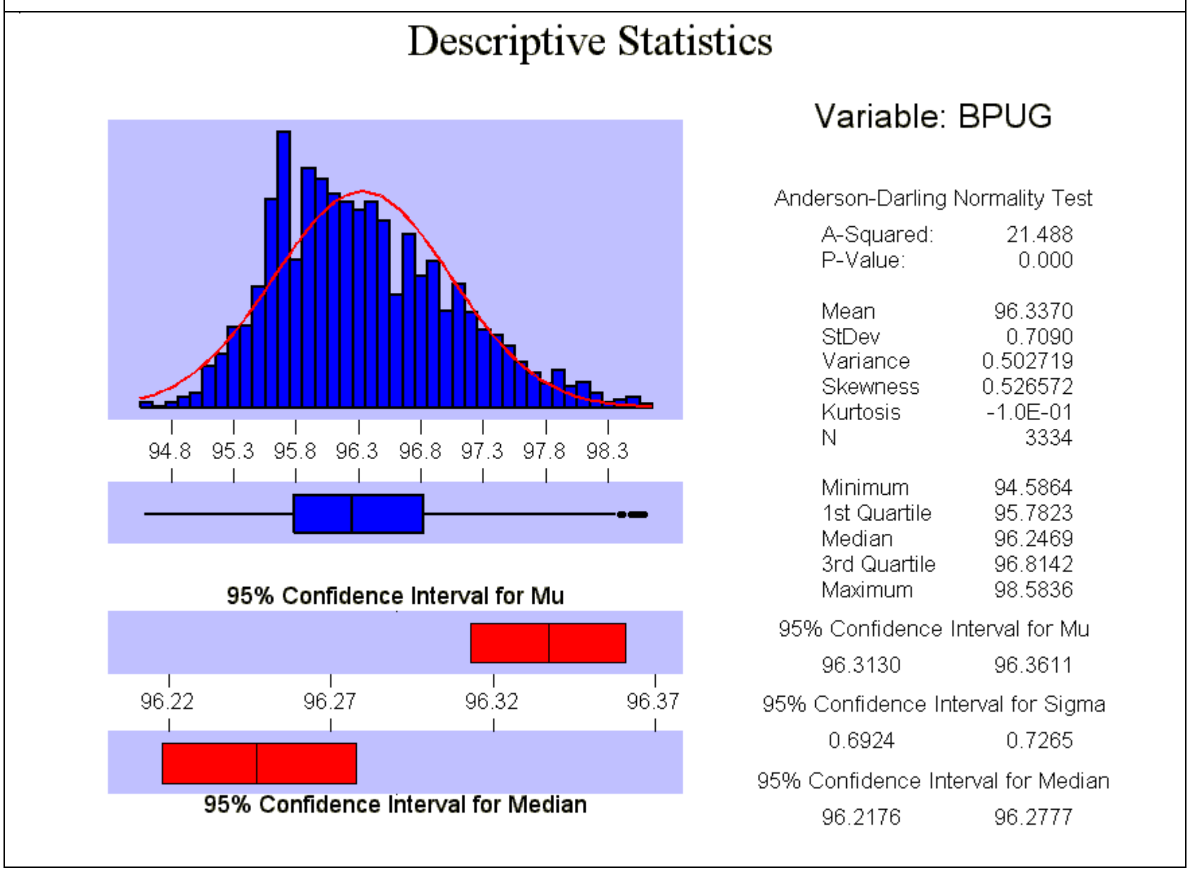
95% Confidence Interval for Median

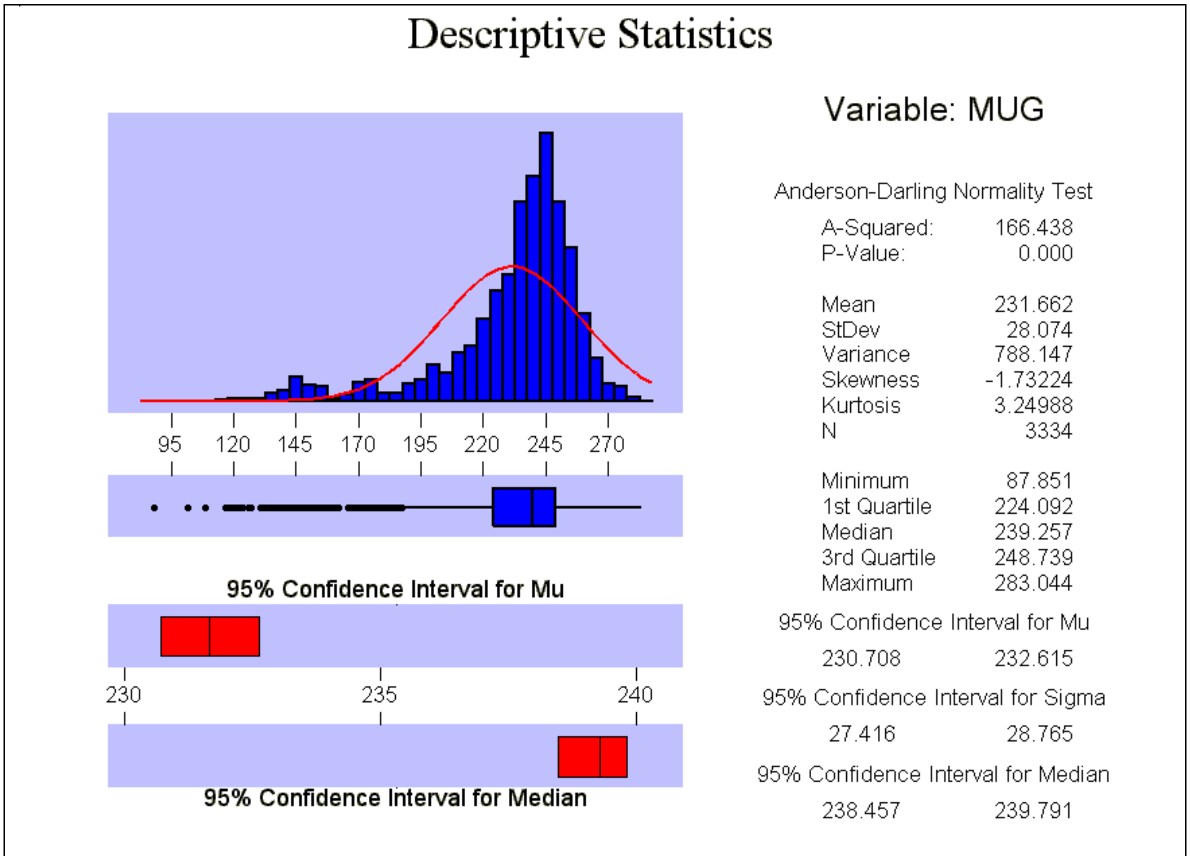
32.6066 33.1794

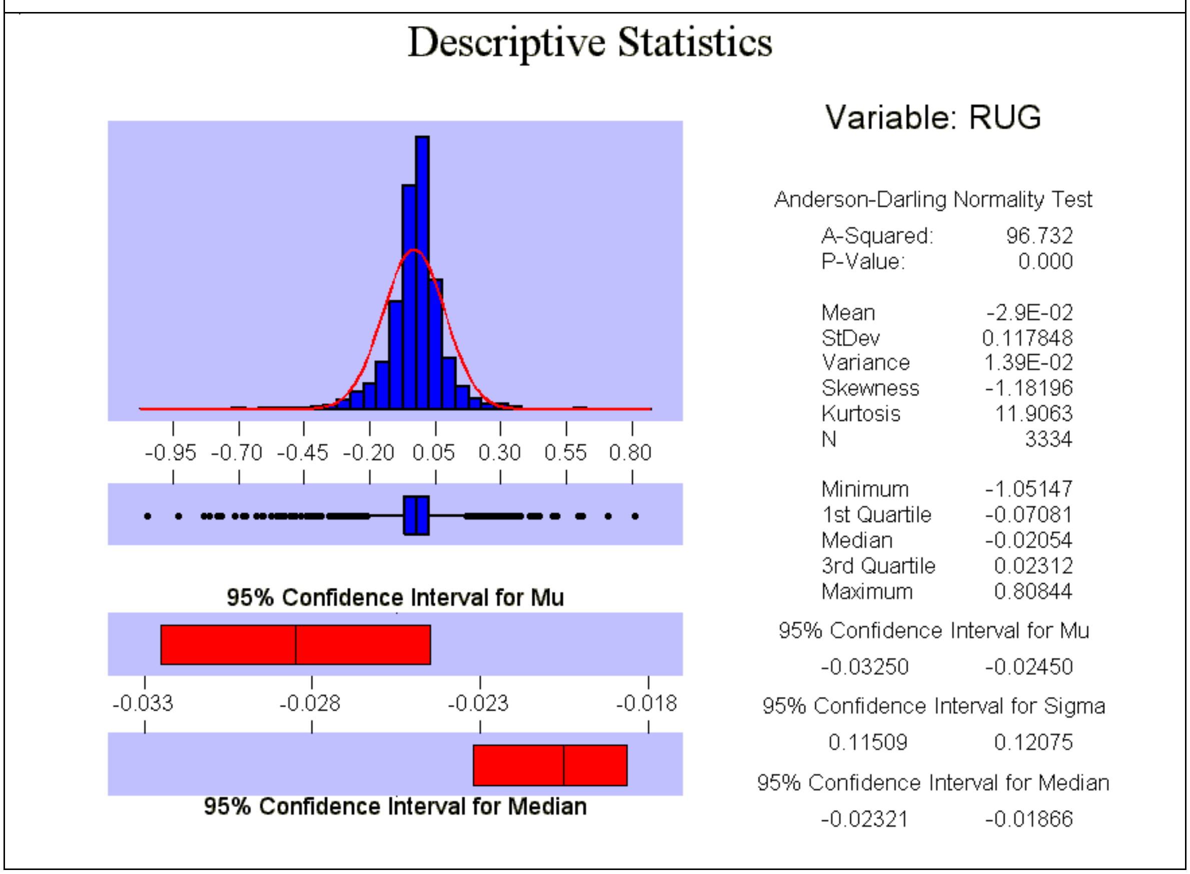

Descriptive Statistics
Variable: RWH
Anderson-Darling Normality Test
A-Squared: 104.139
P-Value: 0.000
Mean 4.56E-03
StDev 2.63E-02
Variance 6.93E-04
Skewness 0.875541
Kurtosis 3.53744
N 3334
Minimum -1.6E-01
1st Quartile -8.2E-03
Median 0.001087
3rd Quartile 0.012151
Maximum 0.132969
95% Confidence Interval for Mu
0.003667 0.005455
95% Confidence Interval for Sigma
0.025716 0.026981
95% Confidence Interval for Median
0.000657 0.001657
-0.144 -0.114 -0.084 -0.054 -0.024 0.006 0.036 0.066 0.096 0.126
95% Confidence Interval for Mu
0.0005 0.0015 0.0025 0.0035 0.0045 0.0055
95% Confidence Interval for Median


Descriptive Statistics
Variable: TUG
Anderson-Darling Normality Test
A-Squared: 19.498
P-Value: 0.000
Mean 25.2246
StDev 6.7959
Variance 46.1839
Skewness -2.9E-01
Kurtosis -7.2E-01
N 3334
Minimum 6.6200
1st Quartile 20.2403
Median 25.4808
3rd Quartile 30.9066
Maximum 39.5213
95% Confidence Interval for Mu
24.9939 25.4554
95% Confidence Interval for Sigma
6.6366 6.9630
95% Confidence Interval for Median
25.2089 25.9278
6 11 16 21 26 31 36
95% Confidence Interval for Mu
25.0 25.5 26.0
95% Confidence Interval for Median

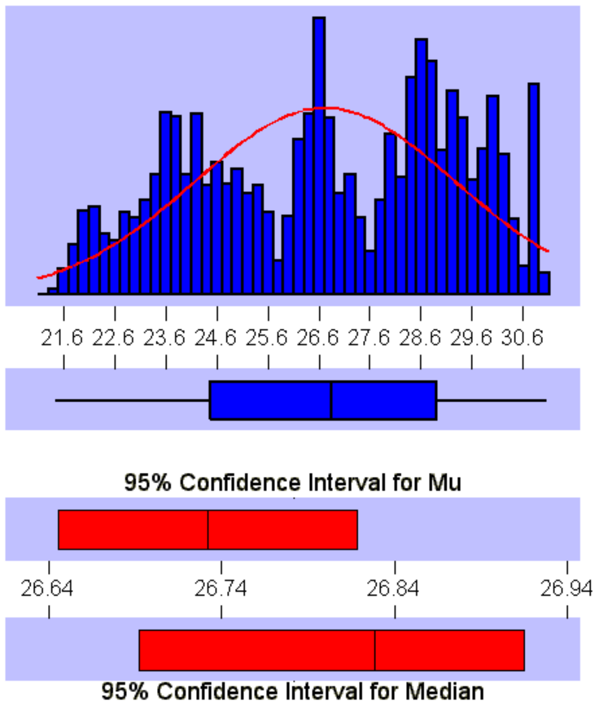

Descriptive Statistics
Variable: RHUG
Anderson-Darling Normality Test
A-Squared: 19.362
P-Value: 0.000
Mean 0.297293
StDev 0.134768
Variance 1.82E-02
Skewness 0.336165
Kurtosis -6.9E-01
N 3334
Minimum 0.041748
1st Quartile 0.185486
Median 0.288330
3rd Quartile 0.388809
Maximum 0.654846
95% Confidence Interval for Mu
0.292717 0.301870
95% Confidence Interval for Sigma
0.131609 0.138083
95% Confidence Interval for Median
0.281616 0.295374
0.06 0.16 0.26 0.36 0.46 0.56 0.66
95% Confidence Interval for Mu
0.28 0.29 0.30
95% Confidence Interval for Median


Descriptive Statistics
Variable: BPUG
Anderson-Darling Normality Test
A-Squared: 21.488
P-Value: 0.000
Mean 96.3370
StDev 0.7090
Variance 0.502719
Skewness 0.526572
Kurtosis -1.0E-01
N 3334
Minimum 94.5864
1st Quartile 95.7823
Median 96.2469
3rd Quartile 96.8142
Maximum 98.5836
95% Confidence Interval for Mu
96.3130 96.3611
95% Confidence Interval for Sigma
0.6924 0.7265
95% Confidence Interval for Median
96.2176 96.2777
94.8 95.3 95.8 96.3 96.8 97.3 97.8 98.3
95% Confidence Interval for Mu
96.22 96.27 96.32 96.37
95% Confidence Interval for Median


Descriptive Statistics
Variable: MUG
95 120 145 170 195 220 245 270
95% Confidence Interval for Mu
230 235 240
95% Confidence Interval for Median
Anderson-Darling Normality Test
A-Squared: 166.438
P-Value: 0.000
Mean 231.662
StDev 28.074
Variance 788.147
Skewness -1.73224
Kurtosis 3.24988
N 3334
Minimum 87.851
1st Quartile 224.092
Median 239.257
3rd Quartile 248.739
Maximum 283.044
95% Confidence Interval for Mu
230.708 232.615
95% Confidence Interval for Sigma
27.416 28.765
95% Confidence Interval for Median
238.457 239.791


Descriptive Statistics
Variable: RUG
-0.95 -0.70 -0.45 -0.20 0.05 0.30 0.55 0.80
95% Confidence Interval for Mu
-0.033 -0.028 -0.023 -0.018
95% Confidence Interval for Median
Anderson-Darling Normality Test
A-Squared: 96.732
P-Value: 0.000
Mean -2.9E-02
StDev 0.117848
Variance 1.39E-02
Skewness -1.18196
Kurtosis 11.9063
N 3334
Minimum -1.05147
1st Quartile -0.07081
Median -0.02054
3rd Quartile 0.02312
Maximum 0.80844
95% Confidence Interval for Mu
-0.03250 -0.02450
95% Confidence Interval for Sigma
0.11509 0.12075
95% Confidence Interval for Median
-0.02321 -0.01866

Descriptive Statistics



Variable: TES

Anderson-Darling Normality Test

A-Squared:	44.919
P-Value:	0.000
Mean	26.7320
StDev	2.5406
Variance	6.45444
Skewness	-2.0E-01
Kurtosis	-1.13793
N	3334
Minimum	21.4515
1st Quartile	24.4673
Median	26.8280
3rd Quartile	28.8920
Maximum	31.0426

95% Confidence Interval for Mu

26.6458 26.8183

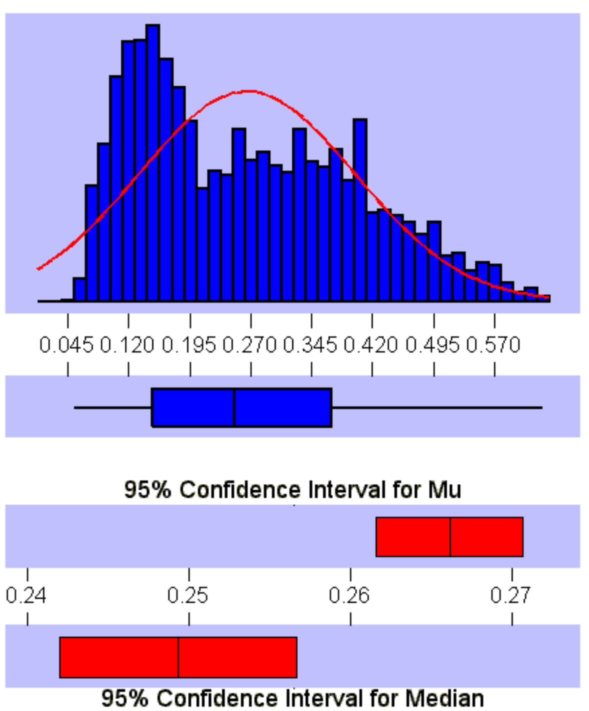
95% Confidence Interval for Sigma

2.4810 2.6031

95% Confidence Interval for Median

26.6920 26.9145

Descriptive Statistics



Variable: RHES

Anderson-Darling Normality Test

A-Squared:	51.691
P-Value:	0.000
Mean	0.266157
StDev	0.133596
Variance	1.78E-02
Skewness	0.481524
Kurtosis	-7.6E-01
N	3334
Minimum	0.051514
1st Quartile	0.148560
Median	0.249267
3rd Quartile	0.368896
Maximum	0.628906

95% Confidence Interval for Mu

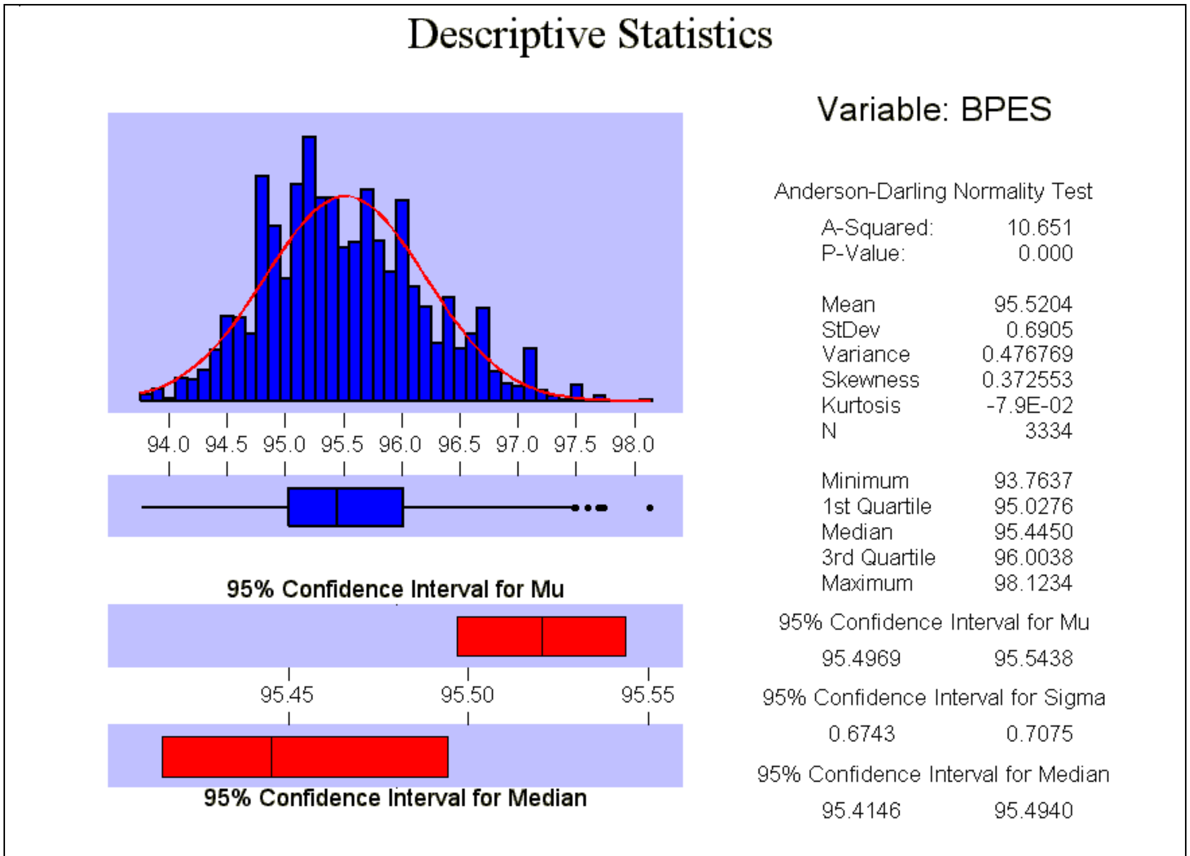
0.261620 0.270693

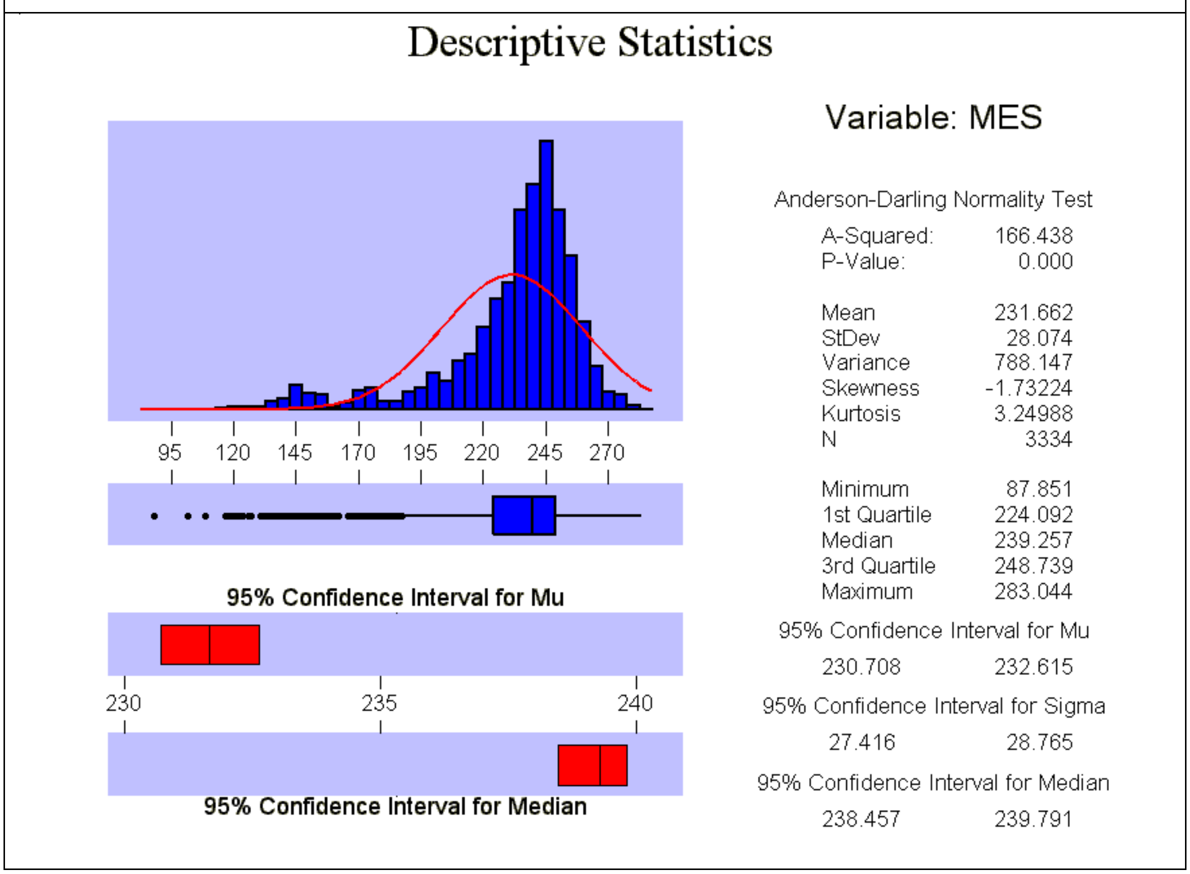
95% Confidence Interval for Sigma

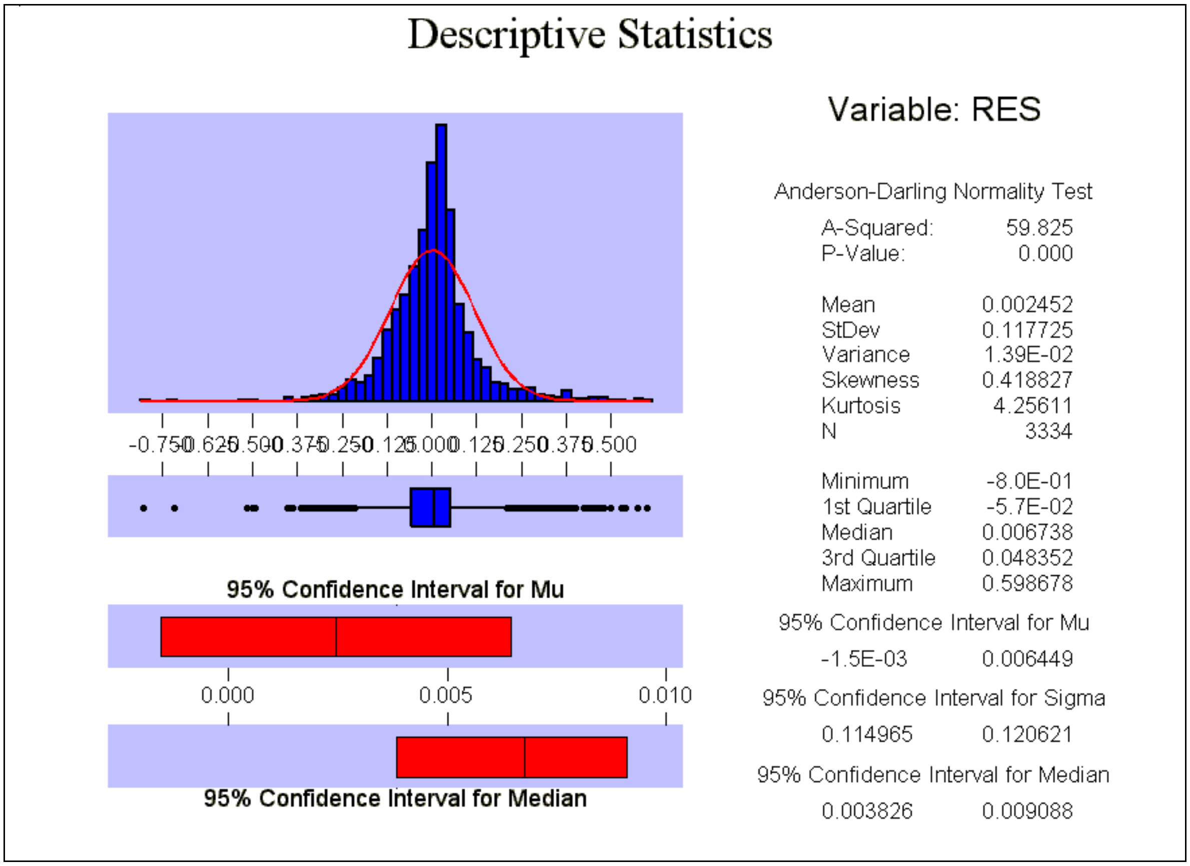
0.130465 0.136882

95% Confidence Interval for Median

0.241943 0.256592


Descriptive Statistics
Variable: BPES
94.0 94.5 95.0 95.5 96.0 96.5 97.0 97.5 98.0
95% Confidence Interval for Mu
95.45 95.50 95.55
95% Confidence Interval for Median
Anderson-Darling Normality Test
A-Squared: 10.651
P-Value: 0.000
Mean 95.5204
StDev 0.6905
Variance 0.476769
Skewness 0.372553
Kurtosis -7.9E-02
N 3334
Minimum 93.7637
1st Quartile 95.0276
Median 95.4450
3rd Quartile 96.0038
Maximum 98.1234
95% Confidence Interval for Mu
95.4969 95.5438
95% Confidence Interval for Sigma
0.6743 0.7075
95% Confidence Interval for Median
95.4146 95.4940


Descriptive Statistics
Variable: MES
95 120 145 170 195 220 245 270
95% Confidence Interval for Mu
230 235 240
95% Confidence Interval for Median
Anderson-Darling Normality Test
A-Squared: 166.438
P-Value: 0.000
Mean 231.662
StDev 28.074
Variance 788.147
Skewness -1.73224
Kurtosis 3.24988
N 3334
Minimum 87.851
1st Quartile 224.092
Median 239.257
3rd Quartile 248.739
Maximum 283.044
95% Confidence Interval for Mu
230.708 232.615
95% Confidence Interval for Sigma
27.416 28.765
95% Confidence Interval for Median
238.457 239.791

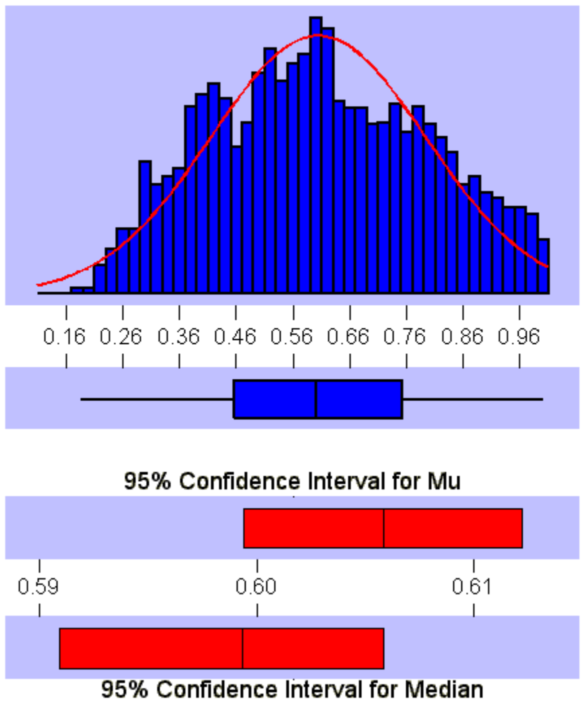

Descriptive Statistics
Variable: RES
-0.750 -0.625 -0.500 -0.375 -0.250 -0.125 0.000 0.125 0.250 0.375 0.500
95% Confidence Interval for Mu
0.000
0.005
0.010
95% Confidence Interval for Median
Anderson-Darling Normality Test
A-Squared: 59.825
P-Value: 0.000
Mean 0.002452
StDev 0.117725
Variance 1.39E-02
Skewness 0.418827
Kurtosis 4.25611
N 3334
Minimum -8.0E-01
1st Quartile -5.7E-02
Median 0.006738
3rd Quartile 0.048352
Maximum 0.598678
95% Confidence Interval for Mu
-1.5E-03 0.006449
95% Confidence Interval for Sigma
0.114965 0.120621
95% Confidence Interval for Median
0.003826 0.009088

APPENDIX B

TRANSFORMATION OF VARIABLES

RH1 = SQRT (RH)
RHES1 = SQRT (RHES)
RHUG1 = SQRT (RHUG)
MSH1 = ln(MSH)

Descriptive Statistics



Variable: RH1

Anderson-Darling Normality Test

A-Squared:	11.026
P-Value:	0.000
Mean	0.605818
StDev	0.189207
Variance	3.58E-02
Skewness	9.80E-02
Kurtosis	-8.2E-01
N	3334
Minimum	0.18488
1st Quartile	0.45661
Median	0.59928
3rd Quartile	0.75236
Maximum	1.00159

95% Confidence Interval for Mu

0.59939 0.61224

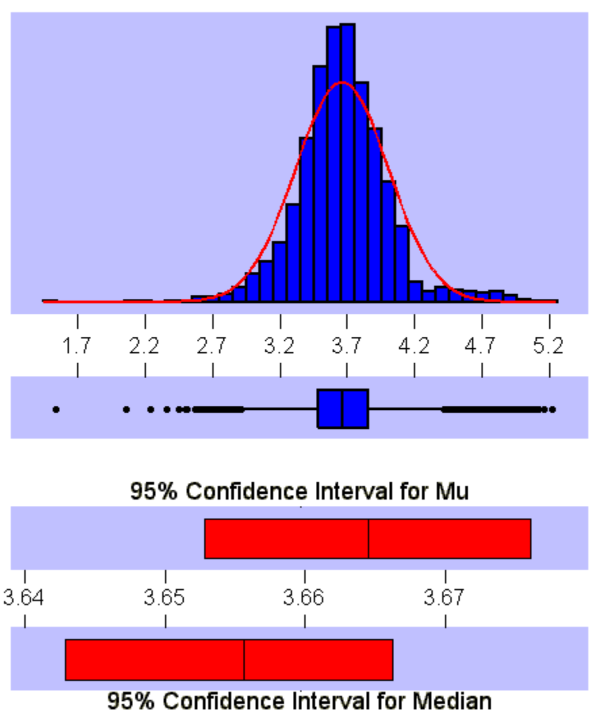
95% Confidence Interval for Sigma

0.18477 0.19386

95% Confidence Interval for Median

0.59085 0.60578

Descriptive Statistics



Variable: MSH1

Anderson-Darling Normality Test

A-Squared:	25.451
P-Value:	0.000
Mean	3.66446
StDev	0.34379
Variance	0.118195
Skewness	0.365821
Kurtosis	2.68784
N	3334
Minimum	1.53526
1st Quartile	3.47507
Median	3.65552
3rd Quartile	3.84643
Maximum	5.21293

95% Confidence Interval for Mu

3.65279 3.67614

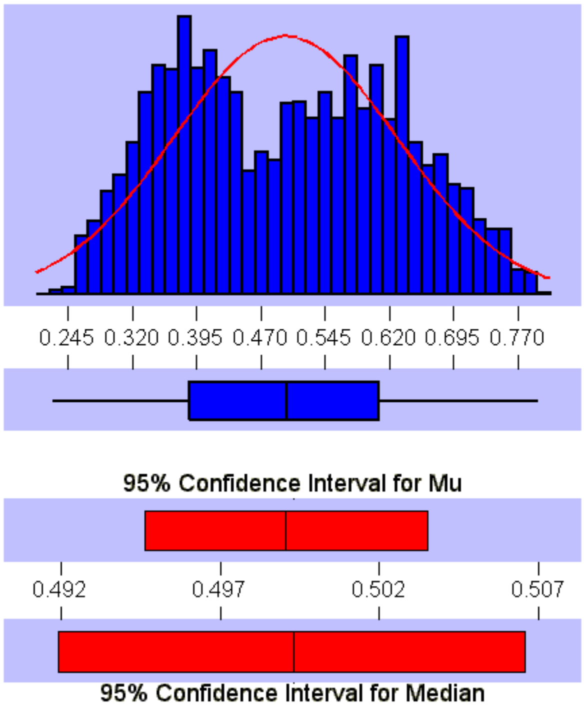
95% Confidence Interval for Sigma

0.33574 0.35225

95% Confidence Interval for Median

3.64276 3.66616

Descriptive Statistics



Variable: RHES1

Anderson-Darling Normality Test

A-Squared:	31.452
P-Value:	0.000
Mean	0.499058
StDev	0.130781
Variance	1.71E-02
Skewness	0.119022
Kurtosis	-1.05062
N	3334
Minimum	0.226966
1st Quartile	0.385434
Median	0.499267
3rd Quartile	0.607368
Maximum	0.793036

95% Confidence Interval for Mu

0.494617 0.503498

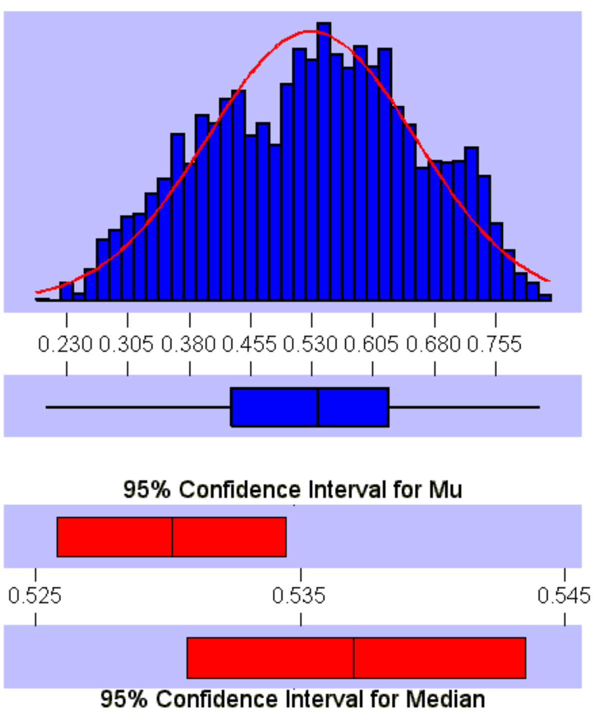
95% Confidence Interval for Sigma

0.127715 0.133998

95% Confidence Interval for Median

0.491877 0.506549

Descriptive Statistics



Variable: RHUG1

Anderson-Darling Normality Test

A-Squared:	9.976
P-Value:	0.000
Mean	0.530139
StDev	0.127481
Variance	1.63E-02
Skewness	-9.8E-02
Kurtosis	-7.7E-01
N	3334
Minimum	0.204323
1st Quartile	0.430681
Median	0.536964
3rd Quartile	0.623546
Maximum	0.809226

95% Confidence Interval for Mu

0.525810 0.534467

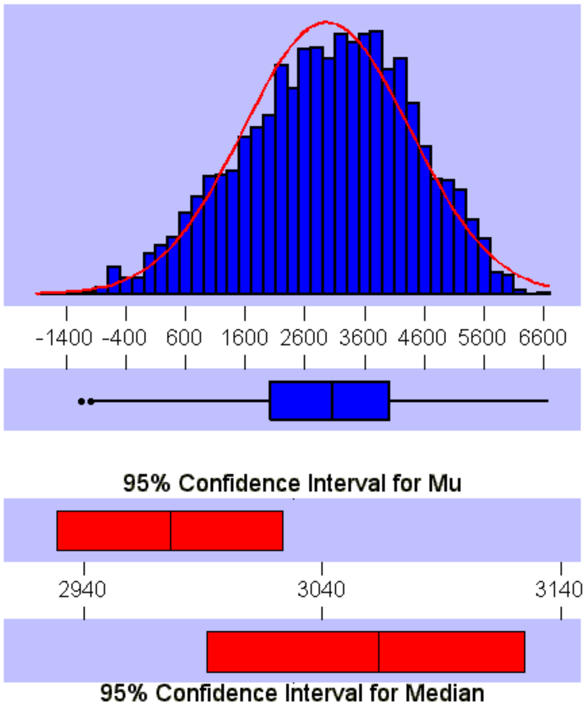
95% Confidence Interval for Sigma

0.124493 0.130617

95% Confidence Interval for Median

0.530675 0.543483

Descriptive Statistics



Variable: T*MAI

Anderson-Darling Normality Test

A-Squared:	6.137
P-Value:	0.000
Mean	2976.17
StDev	1395.96
Variance	1948715
Skewness	-2.4E-01
Kurtosis	-4.3E-01
N	3334
Minimum	-1161.04
1st Quartile	2012.73
Median	3063.56
3rd Quartile	3998.75
Maximum	6673.35

95% Confidence Interval for Mu

2928.76 3023.57

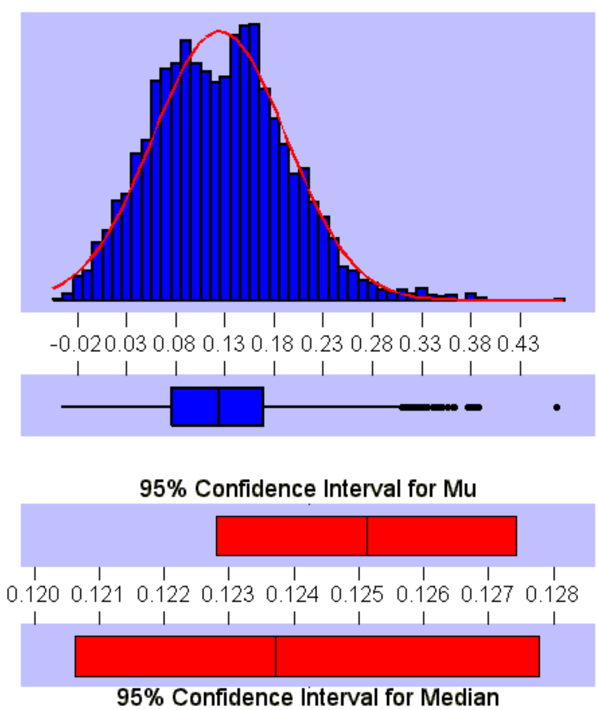
95% Confidence Interval for Sigma

1363.25 1430.30

95% Confidence Interval for Median

2991.38 3124.52

Descriptive Statistics



Variable: T/MAI

Anderson-Darling Normality Test

A-Squared:	4.655
P-Value:	0.000
Mean	0.125121
StDev	0.068157
Variance	4.65E-03
Skewness	0.407072
Kurtosis	0.373175
N	3334
Minimum	-3.6E-02
1st Quartile	0.074930
Median	0.123700
3rd Quartile	0.168579
Maximum	0.466845

95% Confidence Interval for Mu

0.122807 0.127436

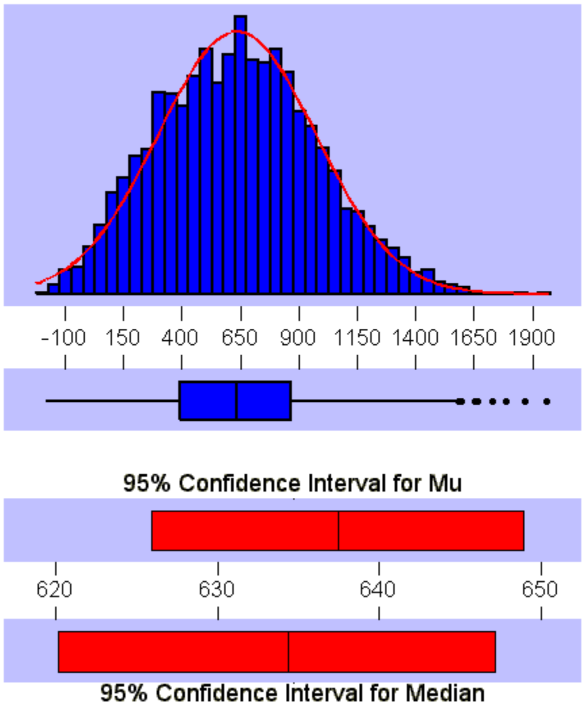
95% Confidence Interval for Sigma

0.066559 0.069833

95% Confidence Interval for Median

0.120610 0.127768

Descriptive Statistics



Variable: T*MWH

Anderson-Darling Normality Test

A-Squared:	2.666
P-Value:	0.000
Mean	637.469
StDev	339.265
Variance	115101
Skewness	0.212678
Kurtosis	-2.4E-01
N	3334
Minimum	-186.91
1st Quartile	385.99
Median	634.36
3rd Quartile	863.05
Maximum	1958.51

95% Confidence Interval for Mu

625.95 648.99

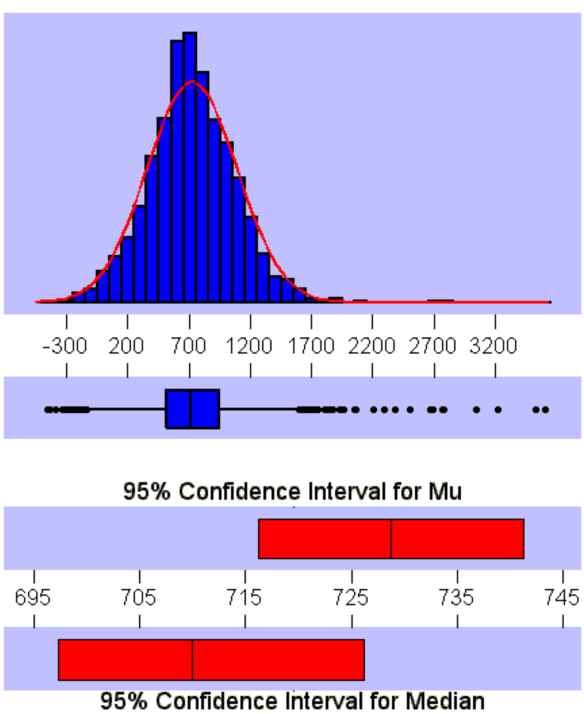
95% Confidence Interval for Sigma

331.31 347.61

95% Confidence Interval for Median

620.06 647.17

Descriptive Statistics



Variable: T*MSH

Anderson-Darling Normality Test

A-Squared:	10.673
P-Value:	0.000
Mean	728.797
StDev	369.405
Variance	136460
Skewness	0.835463
Kurtosis	4.58483
N	3334
Minimum	-466.70
1st Quartile	509.63
Median	709.93
3rd Quartile	943.66
Maximum	3607.07

95% Confidence Interval for Mu

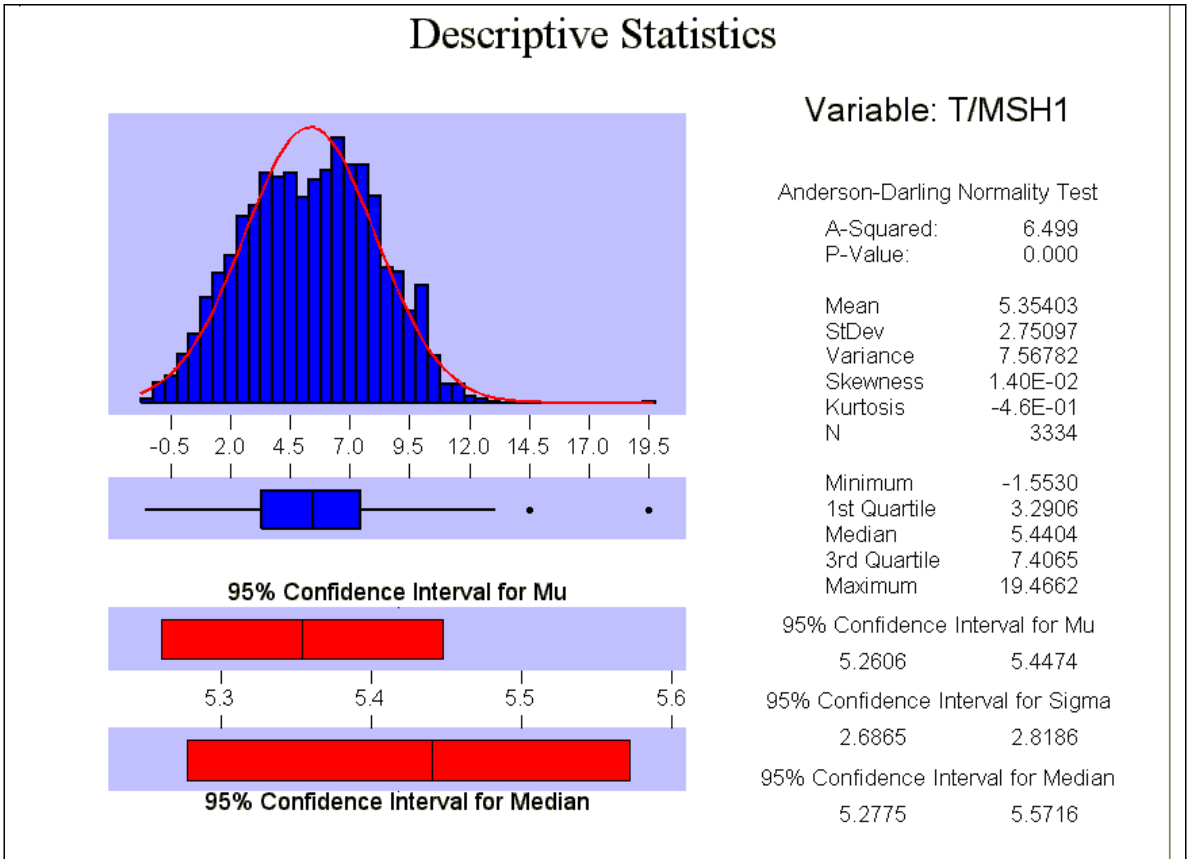
716.25 741.34

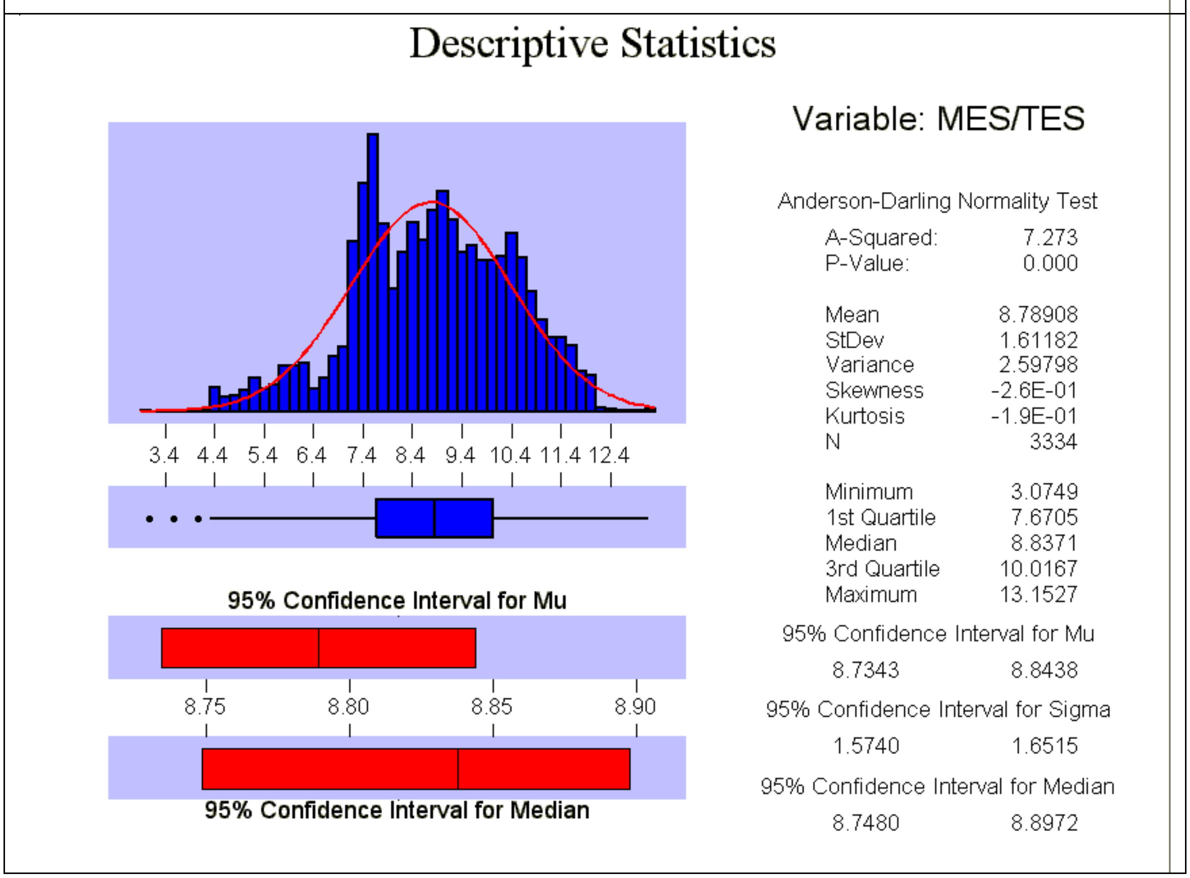
95% Confidence Interval for Sigma

360.75 378.49

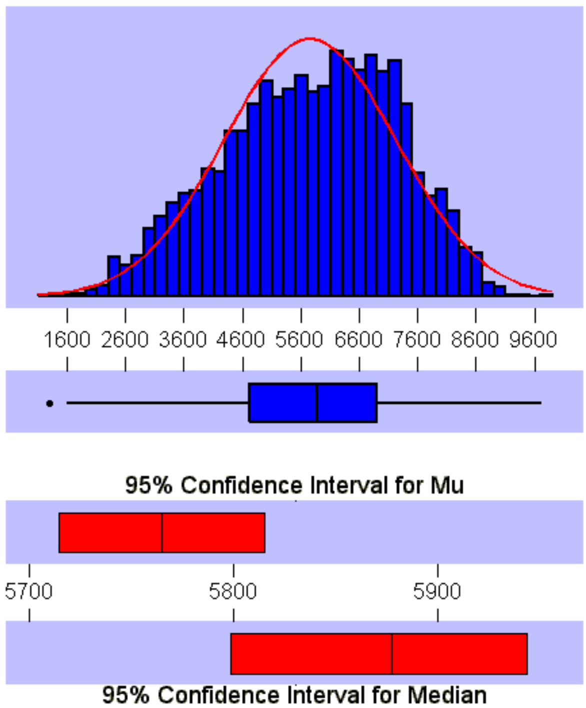
95% Confidence Interval for Median

697.20 726.09


Descriptive Statistics
Variable: T/MSH1
-0.5 2.0 4.5 7.0 9.5 12.0 14.5 17.0 19.5
95% Confidence Interval for Mu
5.3 5.4 5.5 5.6
95% Confidence Interval for Median
Anderson-Darling Normality Test
A-Squared: 6.499
P-Value: 0.000
Mean 5.35403
StDev 2.75097
Variance 7.56782
Skewness 1.40E-02
Kurtosis -4.6E-01
N 3334
Minimum -1.5530
1st Quartile 3.2906
Median 5.4404
3rd Quartile 7.4065
Maximum 19.4662
95% Confidence Interval for Mu
5.2606 5.4474
95% Confidence Interval for Sigma
2.6865 2.8186
95% Confidence Interval for Median
5.2775 5.5716


Descriptive Statistics
Variable: MES/TES
3.4 4.4 5.4 6.4 7.4 8.4 9.4 10.4 11.4 12.4
95% Confidence Interval for Mu
8.75 8.80 8.85 8.90
95% Confidence Interval for Median
Anderson-Darling Normality Test
A-Squared: 7.273
P-Value: 0.000
Mean 8.78908
StDev 1.61182
Variance 2.59798
Skewness -2.6E-01
Kurtosis -1.9E-01
N 3334
Minimum 3.0749
1st Quartile 7.6705
Median 8.8371
3rd Quartile 10.0167
Maximum 13.1527
95% Confidence Interval for Mu
8.7343 8.8438
95% Confidence Interval for Sigma
1.5740 1.6515
95% Confidence Interval for Median
8.7480 8.8972

Descriptive Statistics



Variable: TUG*MUG

Anderson-Darling Normality Test

A-Squared:	10.646
P-Value:	0.000
Mean	5764.47
StDev	1477.87
Variance	2184110
Skewness	-2.4E-01
Kurtosis	-5.9E-01
N	3334
Minimum	1287.21
1st Quartile	4719.77
Median	5876.91
3rd Quartile	6900.39
Maximum	9714.32

95% Confidence Interval for Mu

5714.28 5814.65

95% Confidence Interval for Sigma

1443.23 1514.23

95% Confidence Interval for Median

5797.72 5943.07

APPENDIX C

MINITAB MULTIPLE REGRESSION ANALYSIS OUTPUT

11/15/00 8:45:11 PM

Regression Analysis using all data

Welcome to Minitab, press F1 for help.
Retrieving project from file: X:\WIPP\PsychroMpjFiles\AI shaft\AI SHAFT.MPJ

Results for: AI SHAFT.MTW

Best Subsets Regression: RAI versus T, RH, RH1, BP, MAI, T*MAI, T/MAI

Response is RAI

Vars	R-Sq	R-Sq(adj)	C-p	S	T	RH	RH1	BP	MAI	T*MAI	T/MAI
1	40.7	40.7	311.5	0.049665	X						
1	39.7	39.7	371.3	0.050072						X	
2	41.7	41.6	254.4	0.049268	X						X
2	41.6	41.5	258.6	0.049297	X				X		
3	44.2	44.2	99.5	0.048185	X	X	X				
3	42.9	42.8	180.9	0.048754		X	X			X	
4	**45.0**	**44.9**	**52.3**	**0.047845**	**X**	**X**	**X**				**X**
4	44.9	44.8	59.5	0.047896	X	X	X		X		
5	45.6	45.5	21.0	0.047615	X	X	X			X	X
5	45.0	45.0	52.6	0.047840	X	X	X	X			X
6	45.8	45.7	6.7	0.047506	X	X	X		X	X	X
6	45.6	45.5	21.9	0.047614	X	X	X	X		X	X
7	45.8	45.7	8.0	0.047508	X	X	X	X	X	X	X

Regression Analysis: RAI versus T, RH, RH1, T/MAI

The regression equation is
RAI = - 0.124 + 0.00617 T - 0.302 RH + 0.380 RH1 - 0.228 T/MAI

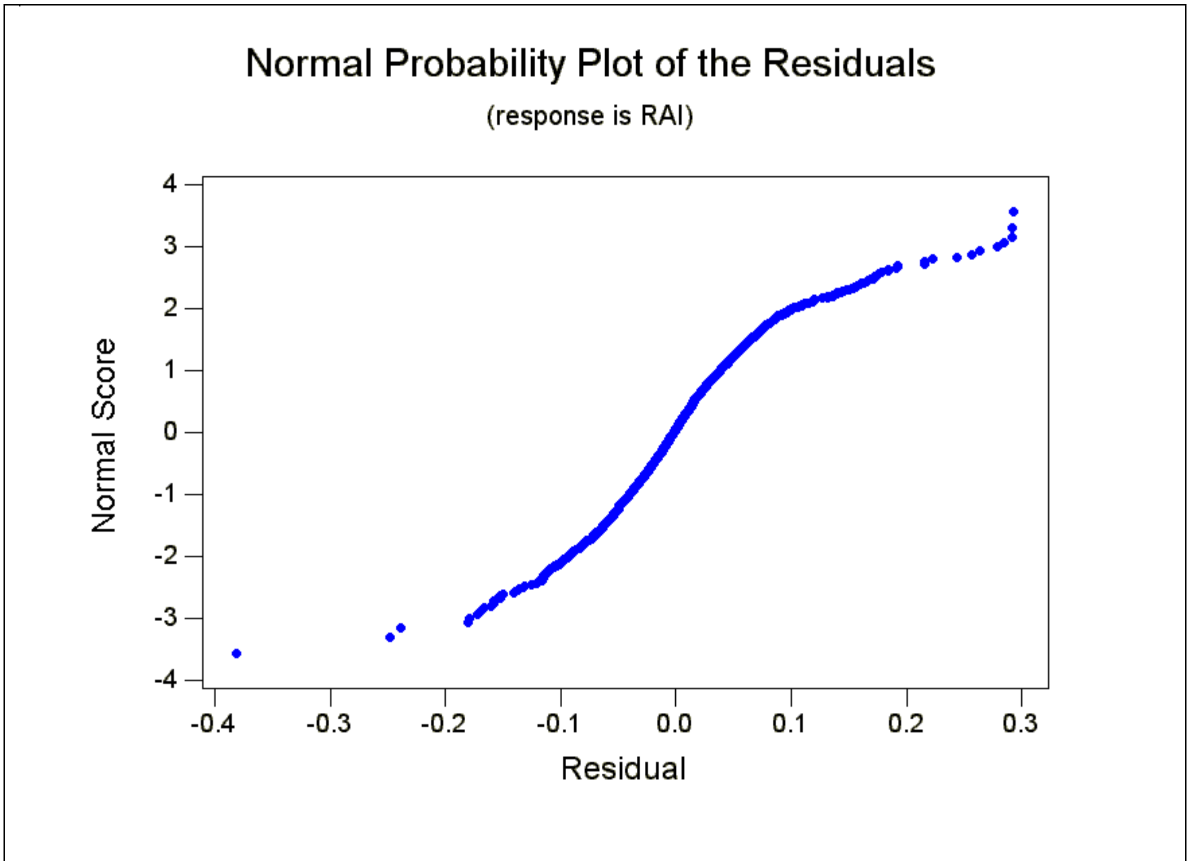
Predictor	Coef	SE Coef	T	P
Constant	-0.124074	0.008355	-14.85	0.000
T	0.0061728	0.0002505	24.64	0.000
RH	-0.30246	0.02141	-14.13	0.000
RH1	0.38045	0.02672	14.24	0.000
T/MAI	-0.22841	0.03280	-6.96	0.000

S = 0.04784   R-Sq = 45.0%   R-Sq(adj) = 44.9%

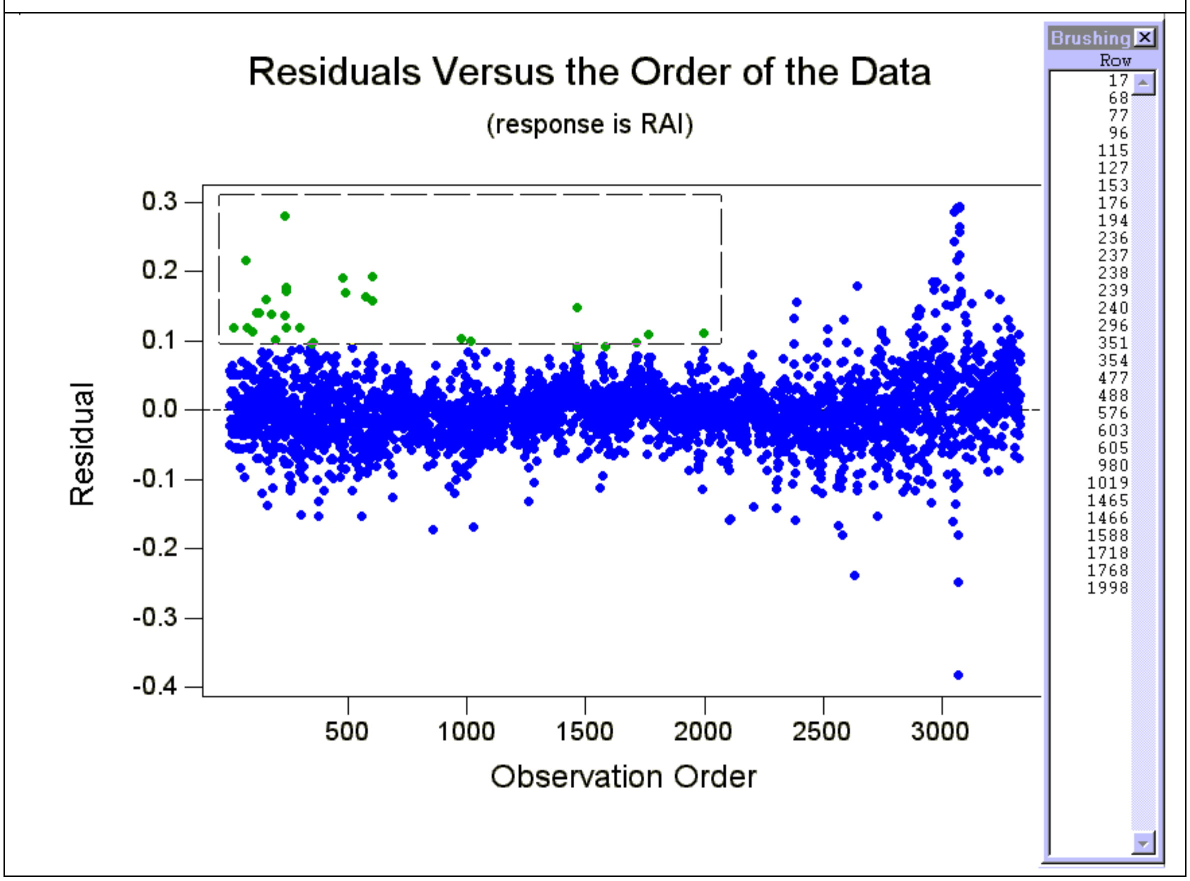
Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	6.2368	1.5592	681.14	0.000
Residual Error	3329	7.6204	0.0023		
Total	3333	13.8572			

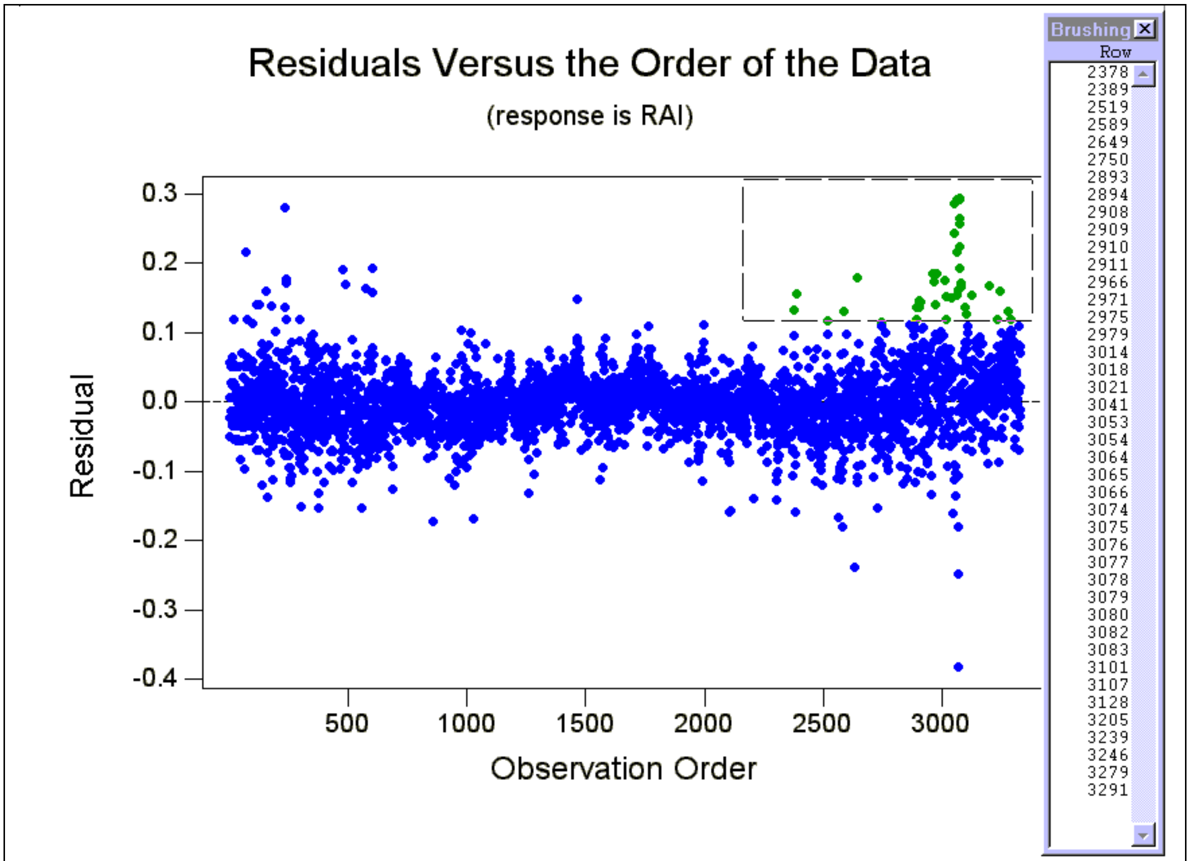
Source	DF	Seq SS
T	1	5.6384
RH	1	0.0019
RH1	1	0.4855
T/MAI	1	0.1110



Normal Probability Plot of the Residuals
(response is RAI)
Normal Score
Residual



Residuals Versus the Order of the Data
(response is RAI)
Residual
Observation Order
Brushing
Row
17
68
77
96
115
127
153
176
194
236
237
238
239
240
296
351
354
477
488
576
603
605
980
1019
1465
1466
1588
1718
1768
1998


Residuals Versus the Order of the Data
(response is RAI)
Residual
Observation Order
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
500
1000
1500
2000
2500
3000
Brushing
Row
2378
2389
2519
2589
2649
2750
2893
2894
2908
2909
2910
2911
2966
2971
2975
2979
3014
3018
3021
3041
3053
3054
3064
3065
3066
3074
3075
3076
3077
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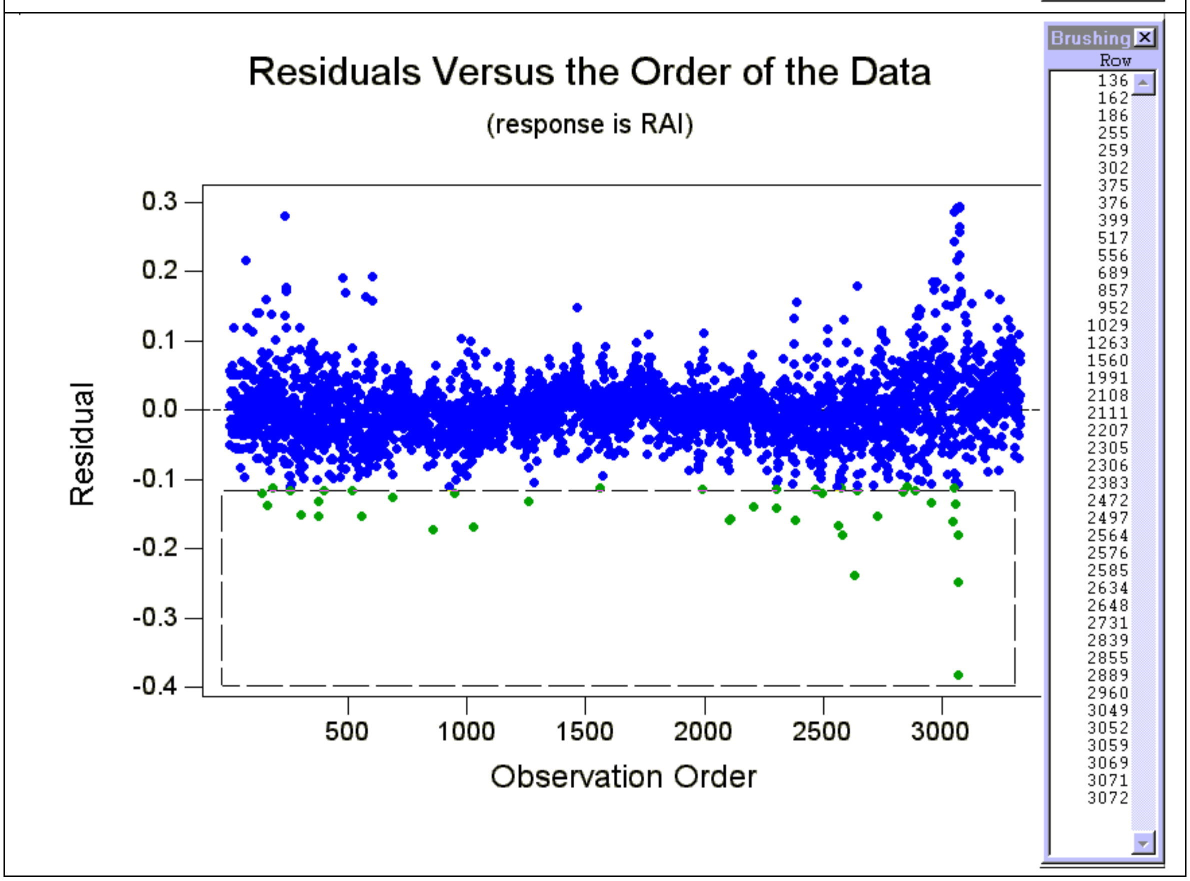
3080
3082
3083
3101
3107
3128
3205
3239
3246
3279
3291


Residuals Versus the Order of the Data
(response is RAI)
Residual
Observation Order
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
500
1000
1500
2000
2500
3000
Brushing
Row
136
162
186
255
259
302
375
376
399
517
556
689
857
952
1029
1263
1560
1991
2108
2111
2207
2305
2306
2383
2472
2497
2564
2576
2585
2634
2648
2731
2839
2855
2889
2960
3049
3052
3059
3069
3071
3072

11/13/00 1:45:16 AM

```
Welcome to Minitab, press F1 for help.
Retrieving worksheet from file: X:\WIPP\PSYCHR~3\AISHAF~1\AISHAF~1.MTW
# Worksheet was saved on Mon Nov 13 2000
Saving file as: X:\WIPP\PsychroMpjFiles\AI shaft\AI SHAFT.MTW
* NOTE  * Existing file replaced.
Subset worksheet AI SHAFT_1.MTW created.
Saving file as: X:\WIPP\PsychroMpjFiles\AI shaft\AI SHAFT.MPJ
* NOTE  * Existing file replaced.
```

Results for: AI SHAFT_1.MTW (WITHOUT THE OUTLIERS

Best Subsets Regression: RAI versus T, RH, ...

Response is RAI

Vars	R-Sq	R-Sq(adj)	C-p	S	T	RH	RH1	BP	X	X1	MAI	T*MAI	T/MAI
1	43.6	43.5	362.6	0.042094	X								
1	42.9	42.9	404.1	0.042335								X	
2	46.2	46.2	195.8	0.041107			X			X			
2	45.8	45.7	222.4	0.041265		X				X			
3	47.3	47.2	127.2	0.040690		X				X		X	
3	47.1	47.1	137.0	0.040749			X			X	X		
4	48.2	48.1	72.0	0.040351	X	X	X						X
4	48.1	48.0	80.0	0.040399	X	X	X				X		
5	48.7	48.6	40.2	0.040151	X	X	X					X	X
5	48.7	48.6	41.4	0.040158	X	X	X			X			X
6	49.1	49.0	16.8	0.040002	X	X	X			X		X	X
6	49.0	48.9	21.3	0.040030	X	X	X				X	X	X
7	49.3	49.2	7.5	0.039938	X	X	X			X	X	X	X
7	49.2	49.1	14.3	0.039980	X	X	X		X	X		X	X
8	49.3	49.2	8.0	0.039935	X	X	X		X	X	X	X	X
8	49.3	49.2	9.5	0.039944	X	X	X	X		X	X	X	X
9	49.3	49.2	10.0	0.039942	X	X	X	X	X	X	X	X	X

Regression Analysis: RAI versus T, RH, RH1, T/MAI

The regression equation is
RAI = - 0.103 + 0.00572 T - 0.264 RH + 0.330 RH1 - 0.227 T/MAI

Predictor	Coef	SE Coef	T	P
Constant	-0.103364	0.007100	-14.56	0.000
T	0.0057231	0.0002141	26.74	0.000
RH	-0.26390	0.01818	-14.52	0.000
RH1	0.32978	0.02268	14.54	0.000
T/MAI	-0.22712	0.02797	-8.12	0.000

S = 0.04035   R-Sq = 48.2%   R-Sq(adj) = 48.1%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	4.9282	1.2320	756.71	0.000
Residual Error	3255	5.2997	0.0016		
Total	3259	10.2279			

Source	DF	Seq SS
T	1	4.4551
RH	1	0.0034
RH1	1	0.3623
T/MAI	1	0.1073

Descriptive Statistics: T, RH, RH1, T/MAI, RAI

Variable	N	Mean	Median	TrMean	StDev	SE Mean
T	3260	18.835	19.523	18.970	9.010	0.158
RH	3260	0.40328	0.36060	0.39226	0.23648	0.00414
RH1	3260	0.60604	0.60050	0.60495	0.18977	0.00332
T/MAI	3260	0.12363	0.12199	0.12180	0.06786	0.00119
RAI	3260	0.06978	0.05947	0.06804	0.05602	0.00098

Variable	Minimum	Maximum	Q1	Q3
T	-5.967	40.050	12.325	25.431
RH	0.03418	1.00317	0.20795	0.56641
RH1	0.18488	1.00159	0.45601	0.75260
T/MAI	-0.03614	0.46685	0.07412	0.16629
RAI	-0.09650	0.22928	0.02983	0.10413

Regression Analysis: RAI versus T, RH1, T/MAI

The regression equation is
RAI = - 0.0139 + 0.00588 T + 0.00577 RH1 - 0.247 T/MAI

Predictor	Coef	SE Coef	T	P
Constant	-0.013896	0.003638	-3.82	0.000
T	0.0058787	0.0002206	26.65	0.000
RH1	0.005768	0.004195	1.37	0.169
T/MAI	-0.24704	0.02882	-8.57	0.000

S = 0.04163   R-Sq = 44.8%   R-Sq(adj) = 44.8%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	4.5849	1.5283	881.84	0.000
Residual Error	3256	5.6429	0.0017		
Total	3259	10.2279			

Source	DF	Seq SS
T	1	4.4551
RH1	1	0.0025
T/MAI	1	0.1273

Results for: AI SHAFT_1.MTW (WITHOUT THE OUTLIERS

Regression Analysis: RAI versus T, RH1, T/MAI

The regression equation is
RAI = - 0.0139 + 0.00588 T + 0.00577 RH1 - 0.247 T/MAI

Predictor	Coef	SE Coef	T	P
Constant	-0.013896	0.003638	-3.82	0.000
T	0.0058787	0.0002206	26.65	0.000
RH1	0.005768	0.004195	1.37	0.169
T/MAI	-0.24704	0.02882	-8.57	0.000

S = 0.04163   R-Sq = 44.8%   R-Sq(adj) = 44.8%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	4.5849	1.5283	881.84	0.000
Residual Error	3256	5.6429	0.0017		
Total	3259	10.2279			

Source	DF	Seq SS
T	1	4.4551
RH1	1	0.0025
T/MAI	1	0.1273

Regression Analysis: RAI versus T, T/MAI

The regression equation is
RAI = - 0.00948 + 0.00582 T - 0.246 T/MAI

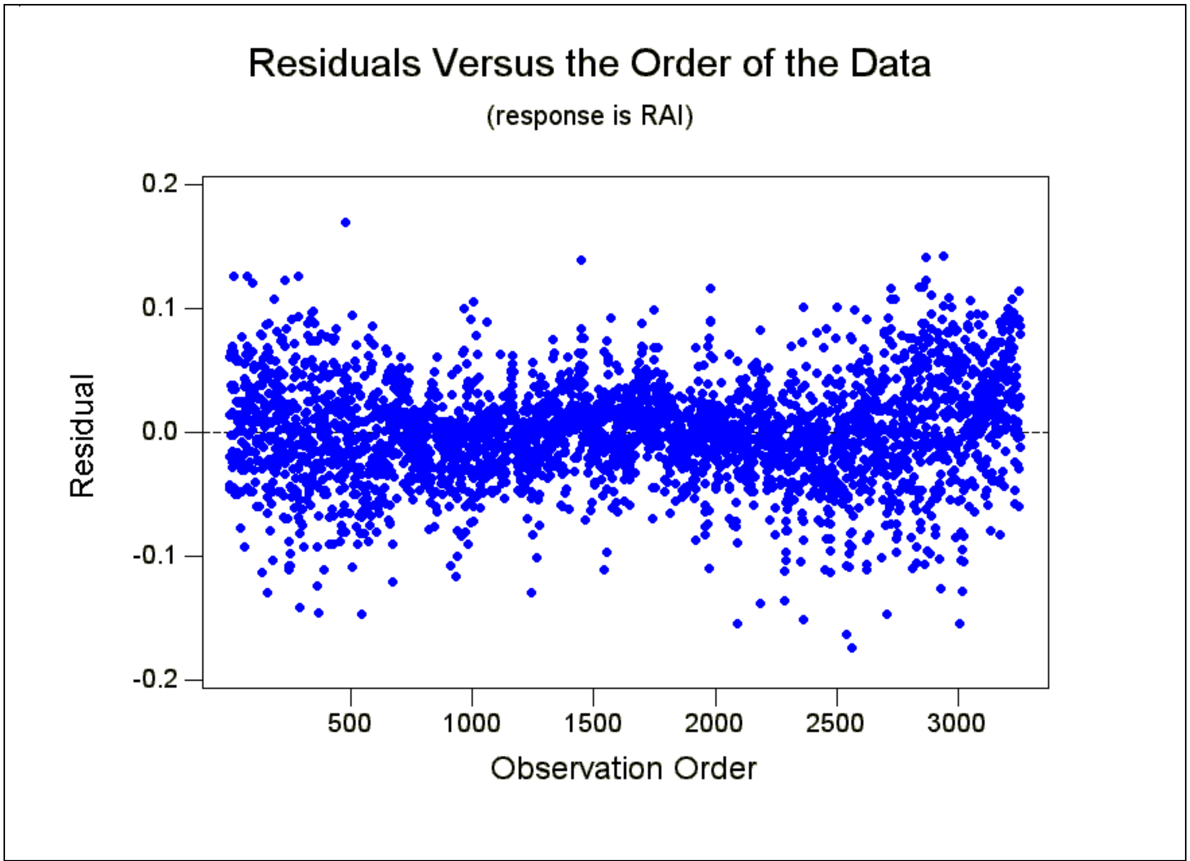
Predictor	Coef	SE Coef	T	P
Constant	-0.009478	0.001706	-5.56	0.000
T	0.0058246	0.0002171	26.83	0.000
T/MAI	-0.24627	0.02882	-8.54	0.000

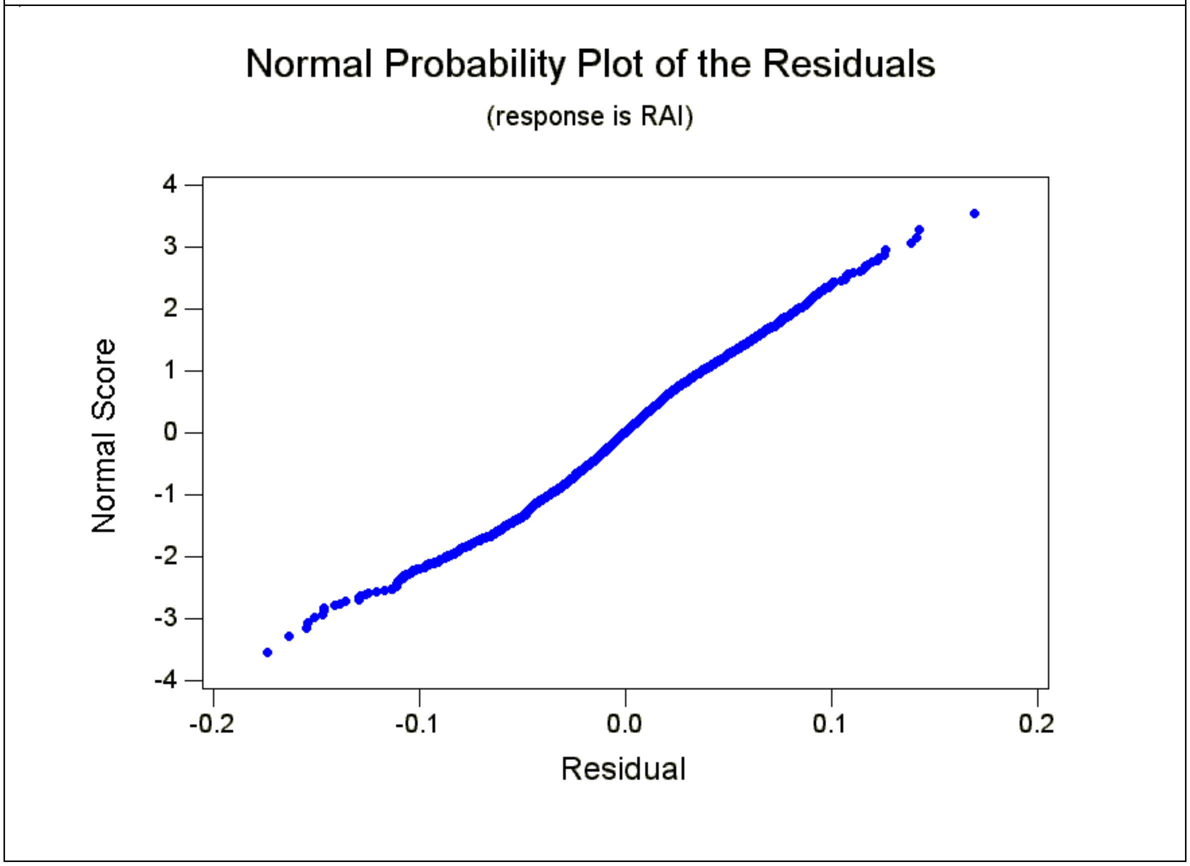
S = 0.04164   R-Sq = 44.8%   R-Sq(adj) = 44.8%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	4.5817	2.2908	1321.46	0.000
Residual Error	3257	5.6462	0.0017		
Total	3259	10.2279			

Source	DF	Seq SS
T	1	4.4551
T/MAI	1	0.1266


Residuals Versus the Order of the Data
(response is RAI)
0.2
0.1
0.0
-0.1
-0.2
Residual
500
1000
1500
2000
2500
3000
Observation Order


Normal Probability Plot of the Residuals
(response is RAI)
4
3
2
1
0
-1
-2
-3
-4
Normal Score
-0.2
-0.1
0.0
0.1
0.2
Residual

11/17/00 3:55:38 PM

```
Welcome to Minitab, press F1 for help.
Retrieving project from file: X:\WIPP\PsychroMpjFiles\SH shaft\SH SHAFT.mpj
```

Results for: SH SHAFT.MTW

Best Subsets Regression: RSH versus T, RH, ...

Response is RSH

Vars	R-Sq	R-Sq(adj)	C-p	S	T	RH	RH1	BP	MSH	MSH1	T*MSH	T/MSH1
1	21.0	20.9	178.1	0.015796		X						
1	19.5	19.5	242.7	0.015940			X					
2	23.0	22.9	89.9	0.015594		X					X	
2	21.7	21.6	148.8	0.015727	X	X						
3	23.8	23.7	56.4	0.015515		X	X				X	
3	23.0	23.0	90.3	0.015592		X			X		X	
4	23.9	23.8	55.0	0.015509		X	X		X		X	
4	23.8	23.7	56.6	0.015513	X	X	X				X	
5	24.7	24.6	20.0	0.015426		X	X		X	X	X	
5	24.7	24.6	21.1	0.015429	X	X	X				X	X
6	25.1	24.9	5.3	0.015390	X	X	X		X	X	X	
6	25.1	24.9	6.2	0.015392		X	X		X	X	X	X
7	25.1	24.9	7.0	0.015392	X	X	X	X	X	X	X	
7	25.1	24.9	7.3	0.015392	X	X	X		X	X	X	X
8	25.1	24.9	9.0	0.015394	X	X	X	X	X	X	X	X

Results for: SH SHAFT.MTW

Regression Analysis: RSH versus RH, RH1, MSH, MSH1, T*MSH

```
The regression equation is
RSH = 0.0278 - 0.0707 RH + 0.0554 RH1 +0.000283 MSH - 0.0134 MSH1
           +0.000009 T*MSH
```

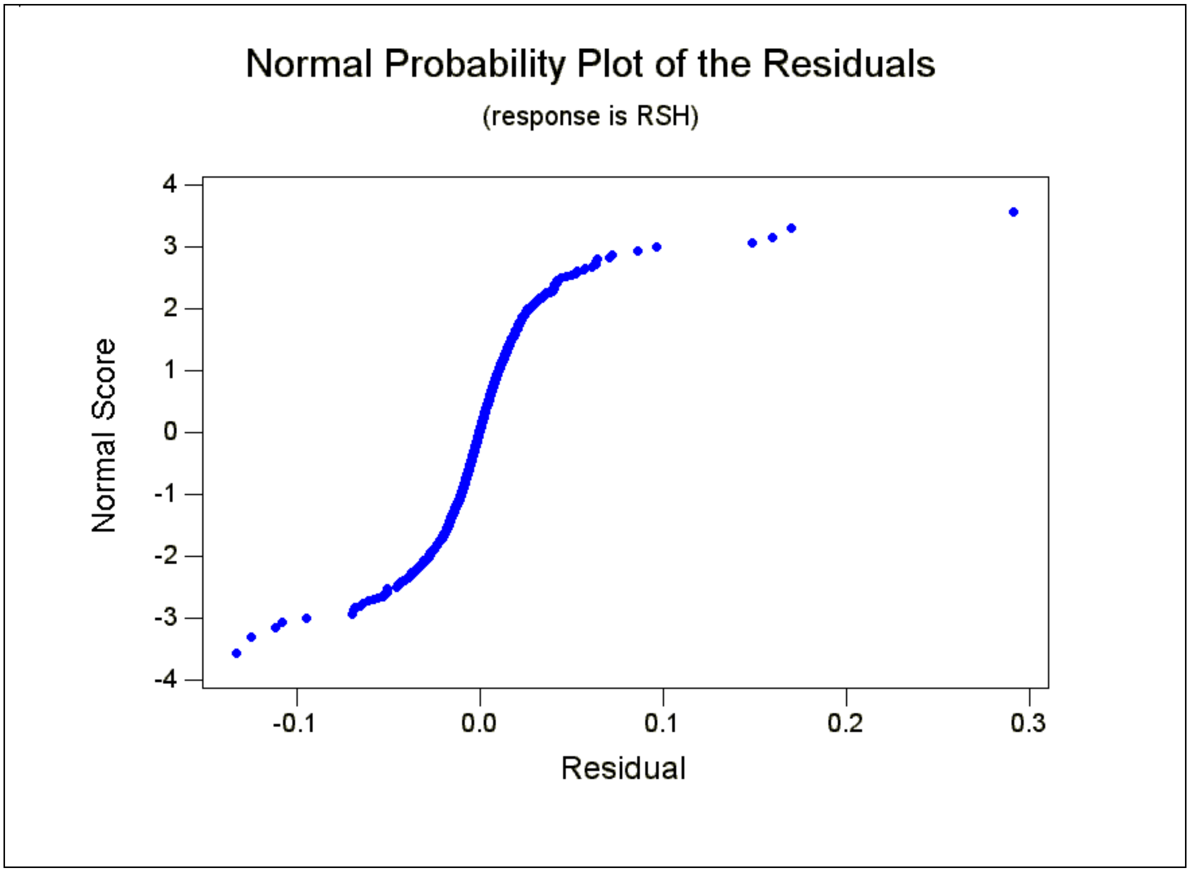
Predictor	Coef	SE Coef	T	P
Constant	0.027762	0.006926	4.01	0.000
RH	-0.070693	0.006948	-10.17	0.000
RH1	0.055440	0.008804	6.30	0.000
MSH	0.00028282	0.00004472	6.32	0.000
MSH1	-0.013405	0.002209	-6.07	0.000
T*MSH	0.00000892	0.00000087	10.30	0.000

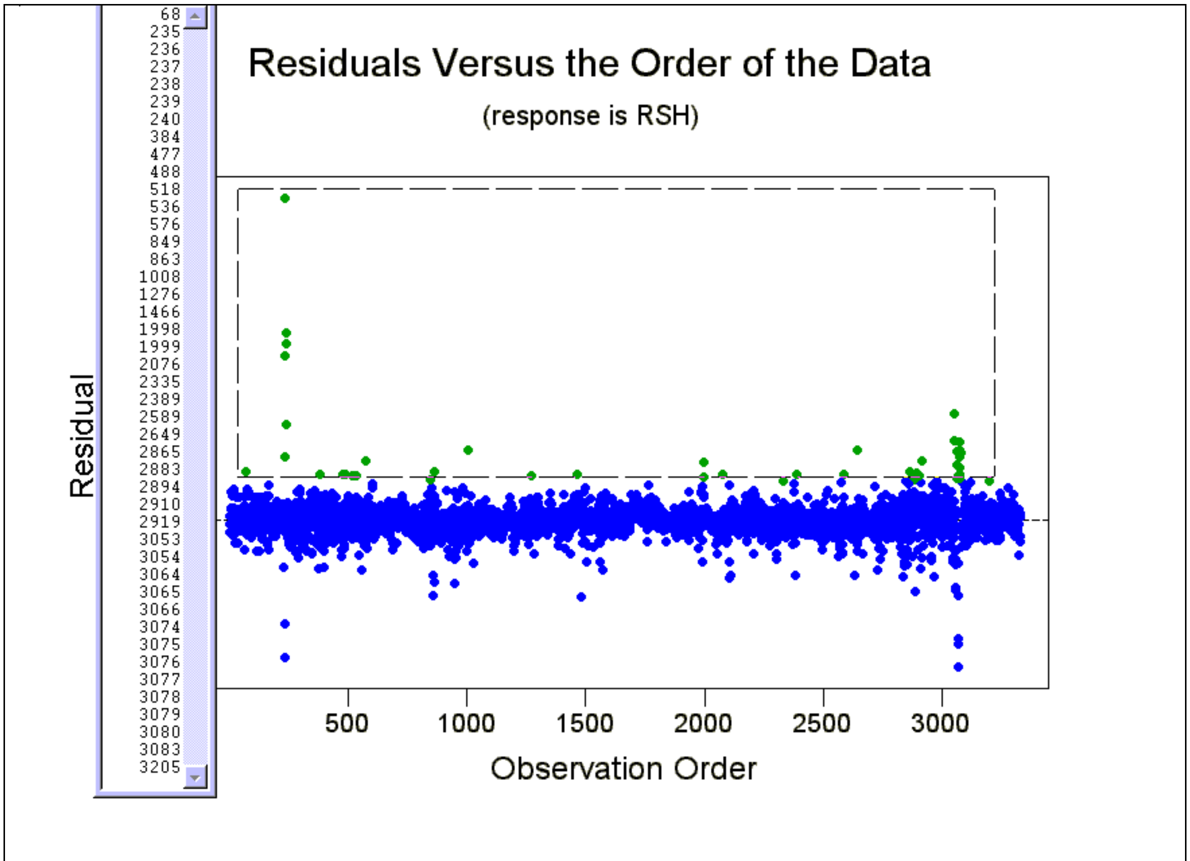
S = 0.01543   R-Sq = 24.7%   R-Sq(adj) = 24.6%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	5	0.259717	0.051943	218.27	0.000
Residual Error	3328	0.791979	0.000238		
Total	3333	1.051696			

Source	DF	Seq SS
RH	1	0.220351
RH1	1	0.003866
MSH	1	0.002491
MSH1	1	0.007741
T*MSH	1	0.025267




Residuals Versus the Order of the Data
(response is RSH)
Residual
Observation Order
500
1000
1500
2000
2500
3000
68
235
236
237
238
239
240
384
477
488
518
536
576
849
863
1008
1276
1466
1998
1999
2076
2335
2389
2589
2649
2865
2883
2894
2910
2919
3053
3054
3064
3065
3066
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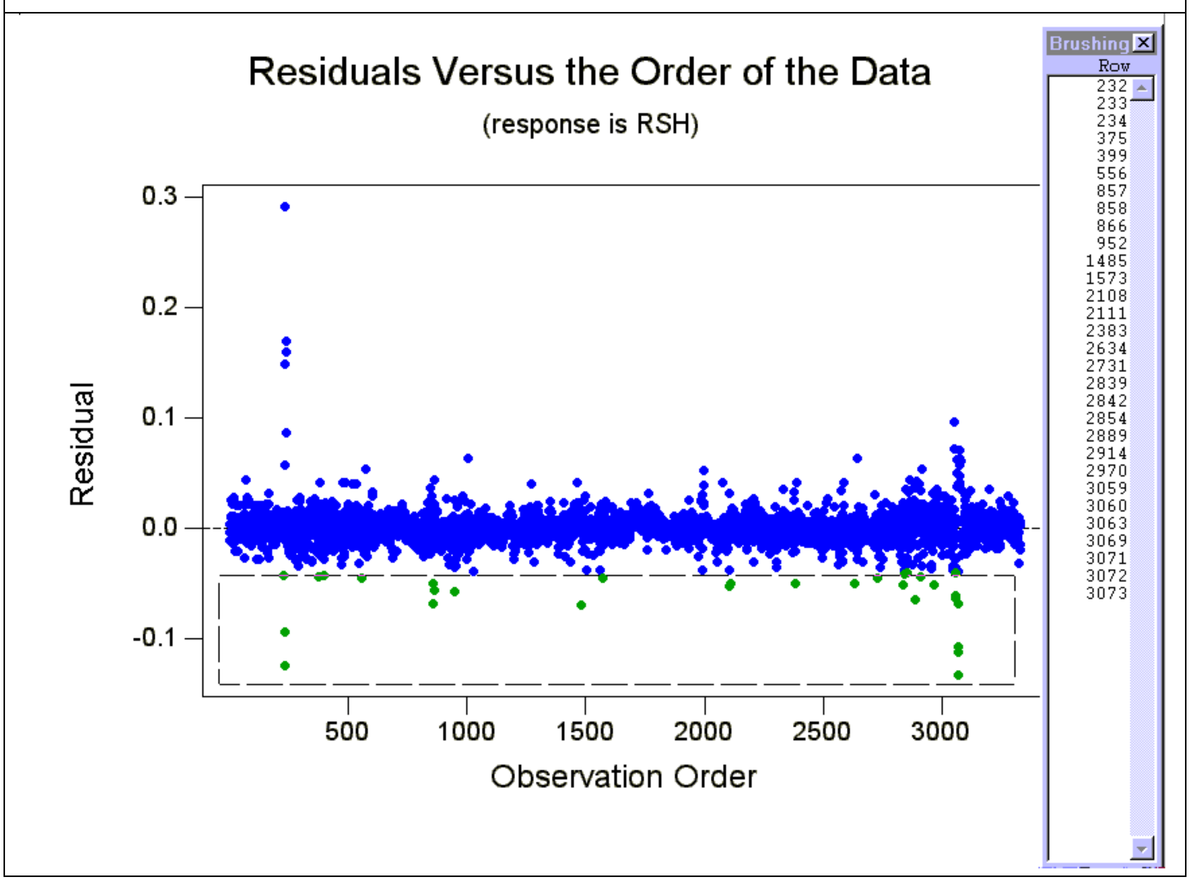
3079
3080
3083
3205


Residuals Versus the Order of the Data
(response is RSH)
Residual
0.3
0.2
0.1
0.0
-0.1
Observation Order
500
1000
1500
2000
2500
3000
Brushing
Row
232
233
234
375
399
556
857
858
866
952
1485
1573
2108
2111
2383
2634
2731
2839
2842
2854
2889
2914
2970
3059
3060
3063
3069
3071
3072
3073

11/15/00 9:52:20 PM

Welcome to Minitab, press F1 for help.
Retrieving project from file: X:\WIPP\PSYCHR~3\SHSHAF~1\SHSHAF~1.MPJ

Results for: SH SHAFT_1.MTW (WITHOUT THE OUTLIERS

Best Subsets Regression: RSH versus T, RH, ...

Response is RSH

Vars	R-Sq	R-Sq(adj)	C-p	S	T	RH	RH1	BP	MSH	MSH1	T*MSH	T/MSH1
1	33.4	33.3	43.7	0.010015		X						
1	31.6	31.6	129.7	0.010148			X					
2	33.9	33.8	21.2	0.0099789		X						X
2	33.8	33.8	24.6	0.0099842	X	X						
3	34.1	34.0	11.9	0.0099628		X	X					X
3	34.1	34.0	14.3	0.0099666	X	X	X					
4	34.2	34.1	10.5	0.0099590		X	X	X				X
4	34.1	34.1	11.6	0.0099607		X	X		X			X
5	34.3	34.2	6.9	0.0099518	X	X	X		X		X	
5	34.3	34.2	8.3	0.0099540		X	X		X		X	X
6	34.4	34.2	5.7	0.0099485	X	X	X	X	X		X	
6	34.3	34.2	7.4	0.0099511		X	X	X	X		X	X
7	34.4	34.2	7.5	0.0099498	X	X	X	X	X	X	X	
7	34.4	34.2	7.7	0.0099500	X	X	X	X	X		X	X
8	34.4	34.2	9.0	0.0099505	X	X	X	X	X	X	X	X

Regression Analysis: RSH versus RH, RH1, MSH, T/MSH1

The regression equation is
RSH = 0.00337 - 0.0444 RH + 0.0206 RH1 +0.000022 MSH +0.000434 T/MSH1

Predictor	Coef	SE Coef	T	P
Constant	0.003370	0.002226	1.51	0.130
RH	-0.044362	0.004545	-9.76	0.000
RH1	0.020609	0.005743	3.59	0.000
MSH	0.00002225	0.00001459	1.52	0.127
T/MSH1	0.00043394	0.00009014	4.81	0.000

S = 0.009961   R-Sq = 34.1%   R-Sq(adj) = 34.1%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	0.163722	0.040930	412.54	0.000
Residual Error	3182	0.315706	0.000099		
Total	3186	0.479428			

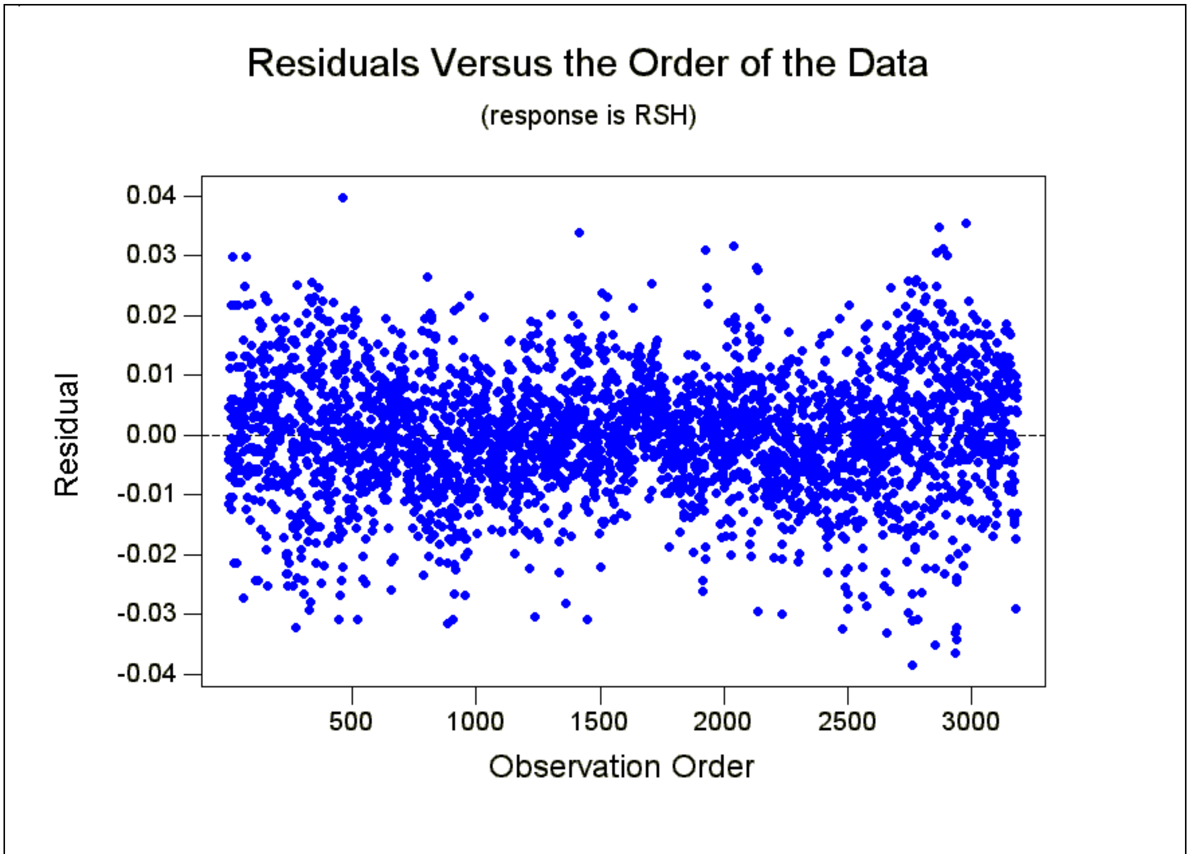
Source	DF	Seq SS
RH	1	0.159945
RH1	1	0.001018
MSH	1	0.000460
T/MSH1	1	0.002299

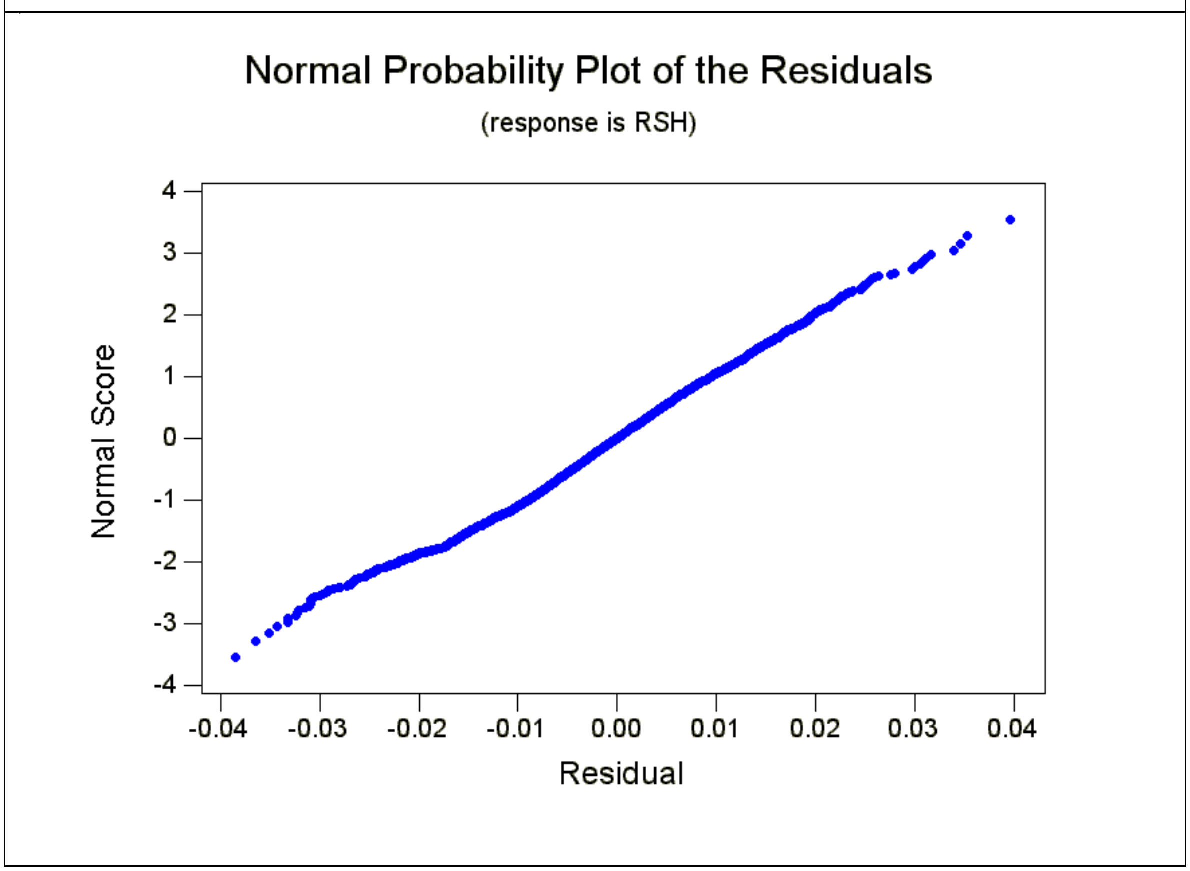
Regression Analysis: RSH versus RH, RH1, T/MSH1

```
The regression equation is
RSH = 0.00549 - 0.0437 RH + 0.0190 RH1 +0.000344 T/MSH1

Predictor         Coef     SE Coef          T        P
Constant      0.005494    0.001737       3.16    0.002
RH           -0.043730    0.004527      -9.66    0.000
RH1           0.018984    0.005644       3.36    0.001
T/MSH1      0.00034396  0.00006815       5.05    0.000

S = 0.009963    R-Sq = 34.1%     R-Sq(adj) = 34.0%

Analysis of Variance

Source            DF          SS          MS         F        P
Regression         3    0.163491    0.054497    549.05    0.000
Residual Error  3183    0.315937    0.000099
Total           3186    0.479428

Source       DF      Seq SS
RH            1    0.159945
RH1           1    0.001018
T/MSH1        1    0.002528
```

Regression Analysis: RSH versus RH1, T/MSH1

```
The regression equation is
RSH = 0.0203 - 0.0347 RH1 +0.000362 T/MSH1

Predictor         Coef     SE Coef          T        P
Constant     0.0203001   0.0008284      24.51    0.000
RH1          -0.034685    0.001005     -34.51    0.000
T/MSH1      0.00036176  0.00006911       5.23    0.000

S = 0.01011     R-Sq = 32.2%     R-Sq(adj) = 32.1%

Analysis of Variance

Source            DF          SS          MS         F        P
Regression         2    0.154231    0.077115    755.03    0.000
Residual Error  3184    0.325197    0.000102
Total           3186    0.479428

Source       DF      Seq SS
RH1           1    0.151432
T/MSH1        1    0.002799
```


Residuals Versus the Order of the Data
(response is RSH)
Residual
0.04
0.03
0.02
0.01
0.00
-0.01
-0.02
-0.03
-0.04
500
1000
1500
2000
2500
3000
Observation Order


Normal Probability Plot of the Residuals
(response is RSH)
Normal Score
4
3
2
1
0
-1
-2
-3
-4
-0.04
-0.03
-0.02
-0.01
0.00
0.01
0.02
0.03
0.04
Residual

11/18/00 7:19:07 PM

Welcome to Minitab, press F1 for help.
Retrieving project from file: X:\WIPP\PsychroMpjFiles\WH shaft\WH SHAFT.mpj

Results for: WH SHAFT.MTW

Best Subsets Regression: RWH versus T, RH, ...

Response is RWH

Vars	R-Sq	R-Sq(adj)	C-p	S	T	RH	RH1	BP	TWH	RHWH	RHWH1	MWH	TWH*MWH	T*MWH
1	2.4	2.4	1288.2	0.026031										X
1	1.6	1.6	1325.9	0.026137	X									
2	8.1	8.1	1019.2	0.025259	X				X					
2	6.7	6.6	1088.2	0.025459									X	X
3	10.9	10.8	888.3	0.024874	X		X		X					
3	10.6	10.5	903.1	0.024917	X	X			X					
4	24.1	24.0	268.5	0.022969	X		X		X		X			
4	23.5	23.4	294.1	0.023050	X		X		X	X				
5	27.6	27.5	101.8	0.022426	X	X	X		X		X			
5	25.2	25.1	214.8	0.022794	X		X		X	X	X			
6	28.7	28.6	52.2	0.022260	X	X	X		X	X	X			
6	27.9	27.8	89.1	0.022381	X	X	X		X		X			X
7	29.0	28.9	40.5	0.022218	X	X	X		X	X	X			X
7	29.0	28.8	43.5	0.022228	X	X	X		X	X	X		X	
8	29.7	29.5	11.5	0.022119	X	X	X		X	X	X	X	X	
8	29.4	29.3	22.6	0.022156	X	X	X		X	X	X	X		X
9	29.7	29.5	10.1	0.022111	X	X	X		X	X	X	X	X	X
9	29.7	29.5	12.0	0.022117	X	X	X	X	X	X	X	X	X	
10	29.8	29.6	11.0	0.022110	X	X	X	X	X	X	X	X	X	X

Regression Analysis: RWH versus T, RH, RH1, TWH, RHWH1, MWH, T*MWH

The regression equation is
RWH = 0.0253 + 0.00863 T - 0.139 RH + 0.556 RH1 - 0.00982 TWH - 0.449 RHWH1
-0.000551 MWH +0.000034 T*MWH

Predictor	Coef	SE Coef	T	P
Constant	0.025343	0.005862	4.32	0.000
T	0.0086311	0.0003570	24.18	0.000
RH	-0.13918	0.01083	-12.85	0.000
RH1	0.55568	0.02241	24.80	0.000
TWH	-0.0098229	0.0002918	-33.66	0.000
RHWH1	-0.44908	0.01704	-26.36	0.000
MWH	-0.0005514	0.0001283	-4.30	0.000
T*MWH	0.00003410	0.00000622	5.48	0.000

S = 0.02232 R-Sq = 28.3% R-Sq(adj) = 28.2%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	7	0.655551	0.093650	187.93	0.000
Residual Error	3326	1.657391	0.000498		
Total	3333	2.312942			

Source	DF	Seq SS
T	1	0.036791
RH	1	0.007682
RH1	1	0.002156
TWH	1	0.208782
RHWH1	1	0.383728
MWH	1	0.001453
T*MWH	1	0.014960

Regression Analysis: RWH versus T, RH, RH1, TWH, RHWH1, MWH

The regression equation is

```
RWH = 0.00480 + 0.00985 T - 0.139 RH + 0.568 RH1 - 0.00984 TWH - 0.466 RHWH1
           +0.000090 MWH
```

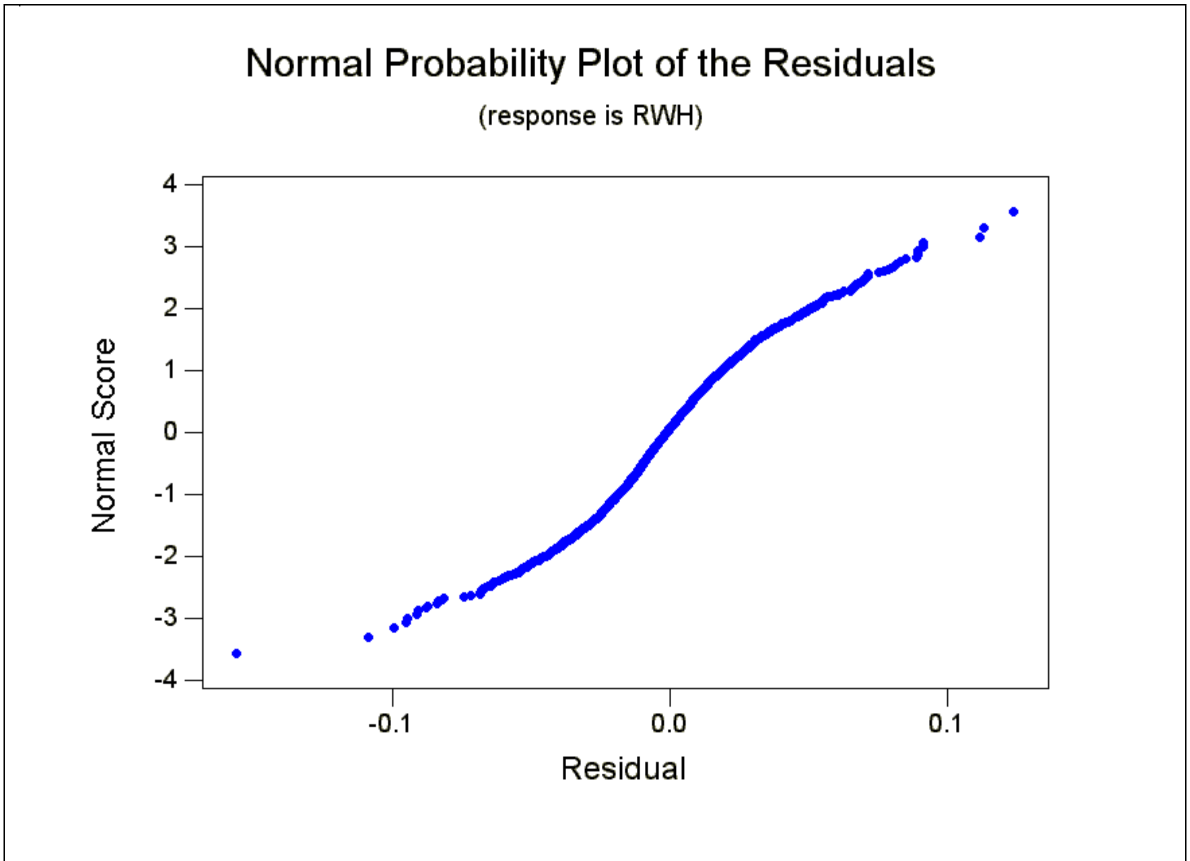
Predictor	Coef	SE Coef	T	P
Constant	0.004804	0.004526	1.06	0.289
T	0.0098541	0.0002798	35.22	0.000
RH	-0.13945	0.01087	-12.82	0.000
RH1	0.56819	0.02239	25.38	0.000
TWH	-0.0098362	0.0002931	-33.56	0.000
RHWH1	-0.46574	0.01684	-27.66	0.000
MWH	0.00008984	0.00005284	1.70	0.089

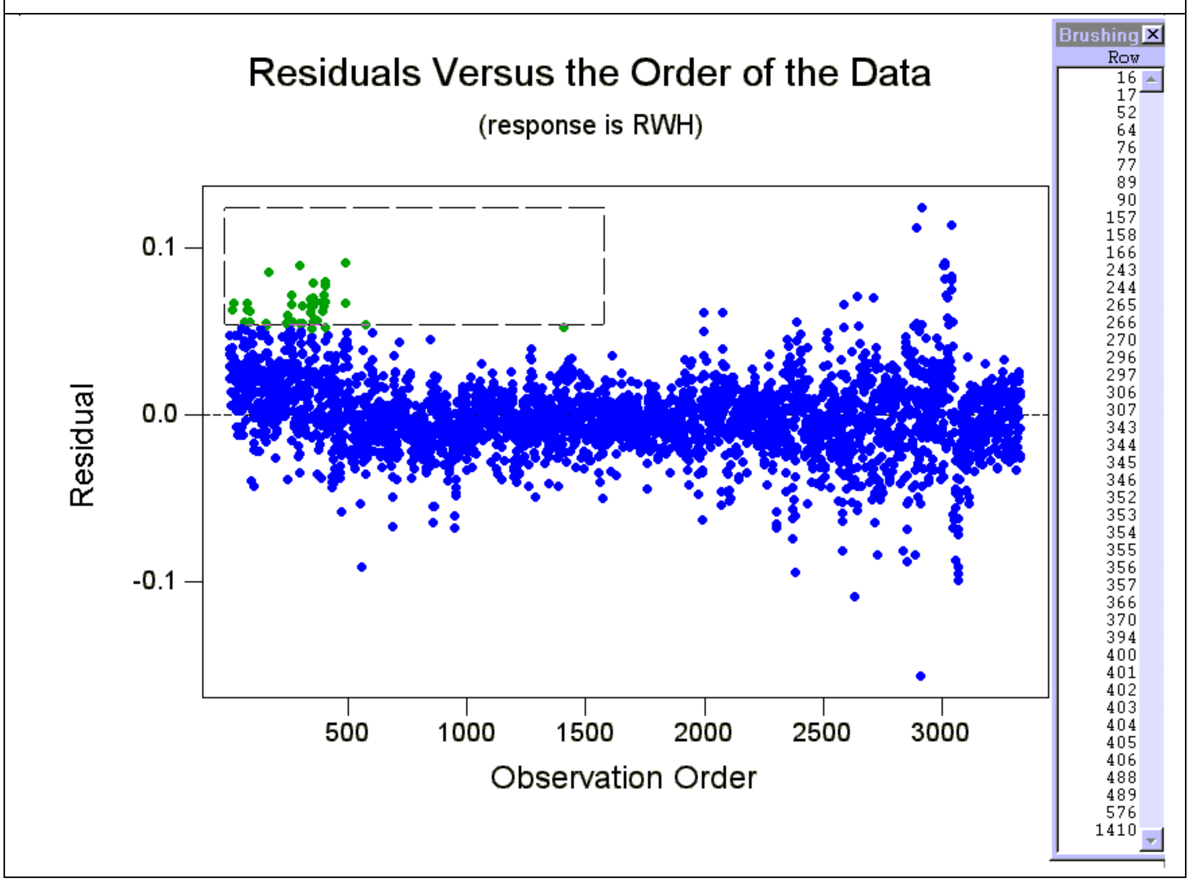
S = 0.02242   R-Sq = 27.7%   R-Sq(adj) = 27.6%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	6	0.64059	0.10677	212.40	0.000
Residual Error	3327	1.67235	0.00050		
Total	3333	2.31294			

Source	DF	Seq SS
T	1	0.03679
RH	1	0.00768
RH1	1	0.00216
TWH	1	0.20878
RHWH1	1	0.38373
MWH	1	0.00145


Normal Probability Plot of the Residuals
(response is RWH)
Normal Score
4
3
2
1
0
-1
-2
-3
-4
-0.1
0.0
0.1
Residual


Residuals Versus the Order of the Data
(response is RWH)
Residual
0.1
0.0
-0.1
500
1000
1500
2000
2500
3000
Observation Order
Brushing
Row
16
17
52
64
76
77
89
90
157
158
166
243
244
265
266
270
296
297
306
307
343
344
345
346
352
353
354
355
356
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366
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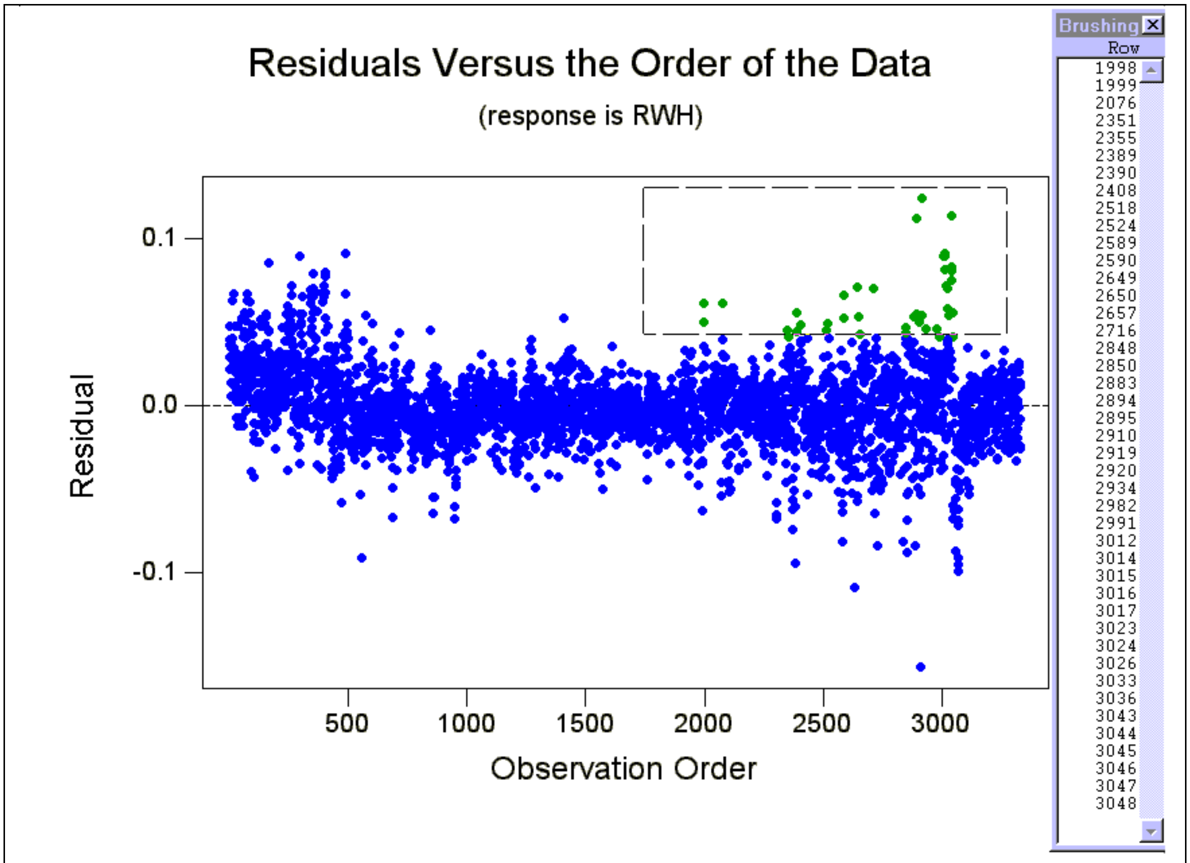
394
400
401
402
403
404
405
406
488
489
576
1410


Residuals Versus the Order of the Data
(response is RWH)
Residual
0.1
0.0
-0.1
500
1000
1500
2000
2500
3000
Observation Order
Brushing
Row
1998
1999
2076
2351
2355
2389
2390
2408
2518
2524
2589
2590
2649
2650
2657
2716
2848
2850
2883
2894
2895
2910
2919
2920
2934
2982
2991
3012
3014
3015
3016
3017
3023
3024
3026
3033
3036
3043
3044
3045
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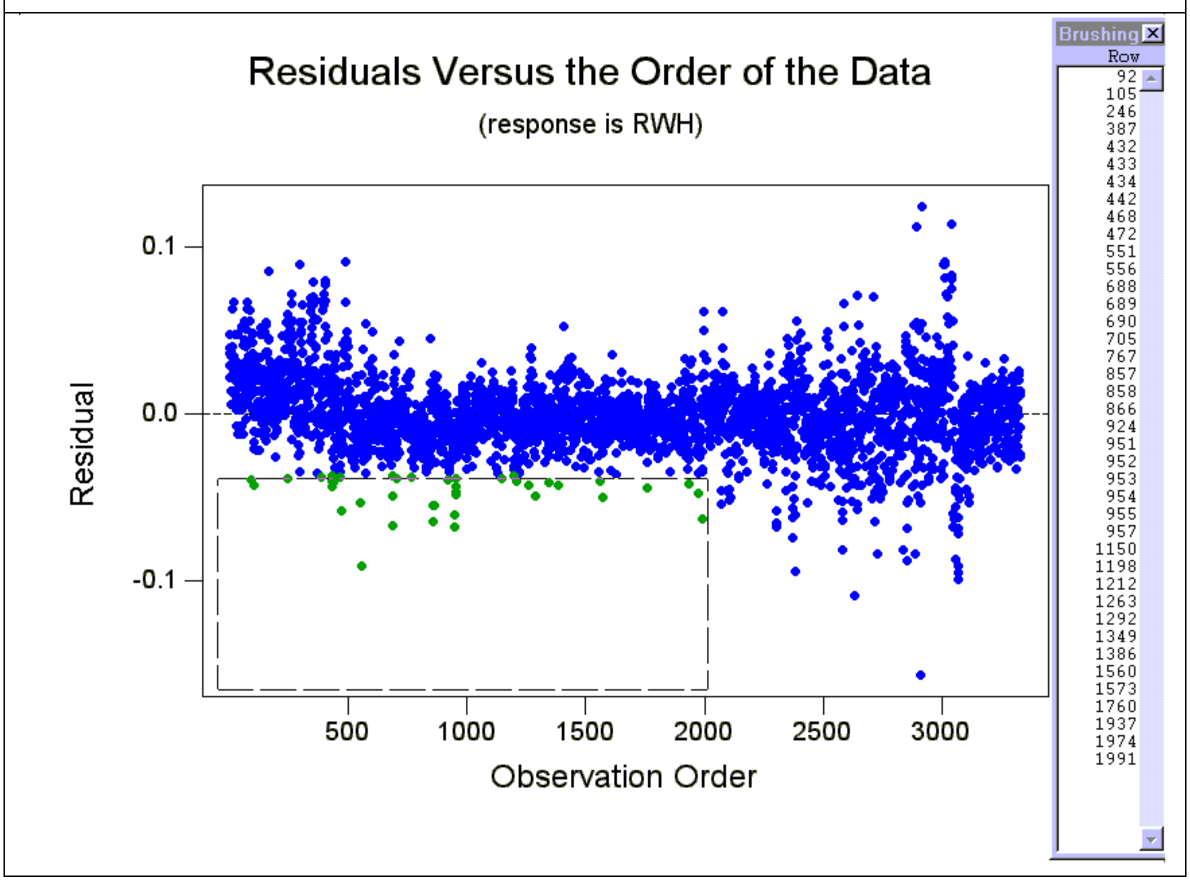
3047
3048


Residuals Versus the Order of the Data
(response is RWH)
Residual
0.1
0.0
-0.1
500
1000
1500
2000
2500
3000
Observation Order
Brushing
Row
92
105
246
387
432
433
434
442
468
472
551
556
688
689
690
705
767
857
858
866
924
951
952
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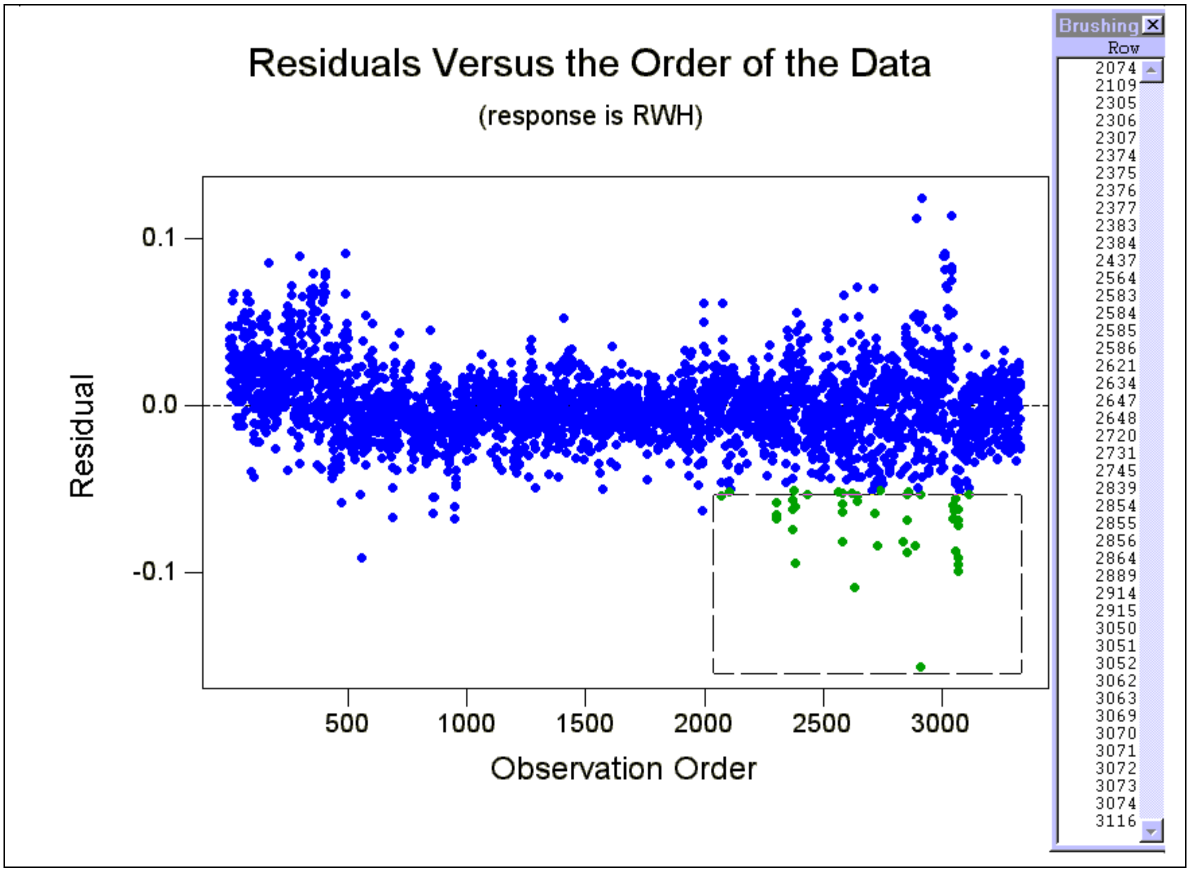
1573
1760
1937
1974
1991


Residuals Versus the Order of the Data
(response is RWH)
Residual
0.1
0.0
-0.1
500
1000
1500
2000
2500
3000
Observation Order
Brushing
Row
2074
2109
2305
2306
2307
2374
2375
2376
2377
2383
2384
2437
2564
2583
2584
2585
2586
2621
2634
2647
2648
2720
2731
2745
2839
2854
2855
2856
2864
2889
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3074
3116

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```
Welcome to Minitab, press F1 for help.
Retrieving project from file: X:\WIPP\PSYCHR~3\WHSHAF~1\WHSHAF~1.MPJ
```

Results for: WH SHAFT_1.MTW (WITHOUT THE OUTLIERS

Best Subsets Regression: RWH versus TWH, RHWH, RHWH1, MWH, TWH*MWH

Response is RWH

Vars	R-Sq	R-Sq(adj)	C-p	S	TWH	RHWH	RHWH1	MWH	TWH*MWH
1	1.1	1.0	48.3	0.015863		X			
1	0.9	0.9	53.0	0.015875			X		
2	1.3	1.3	42.6	0.015845		X	X		
2	1.3	1.2	44.2	0.015849		X		X	
3	1.5	1.4	38.9	0.015833		X	X	X	
3	1.5	1.4	39.0	0.015833	X			X	X
4	2.4	2.3	13.0	0.015762	X	X		X	X
4	2.3	2.1	17.6	0.015774	X		X	X	X
5	2.7	2.6	6.0	0.015741	X	X	X	X	X

Best Subsets Regression: RWH versus T, RH, RH1, BP, MWH, T*MWH

Response is RWH

Vars	R-Sq	R-Sq(adj)	C-p	S	T	RH	RH1	BP	MWH	T*MWH
1	1.4	1.4	38.3	0.015836		X				
1	1.3	1.3	40.9	0.015843			X			
2	1.6	1.6	33.0	0.015820		X			X	
2	1.6	1.5	35.5	0.015827			X		X	
3	2.0	1.9	25.5	0.015797		X			X	X
3	1.9	1.8	27.8	0.015804			X		X	X
4	2.7	2.6	4.7	0.015740	X	X			X	X
4	2.6	2.5	7.9	0.015748	X		X		X	X
5	2.7	2.6	5.4	0.015739	X	X	X		X	X
5	2.7	2.6	6.2	0.015741	X	X		X	X	X
6	2.8	2.6	7.0	0.015741	X	X	X	X	X	X

Best Subsets Regression: RWH versus T, RH, ...

Response is RWH

Vars	R-Sq	R-Sq(adj)	C-p	S	T	RH	RH1	BP	TWH	RHWH	RHWH1	MWH	TWH*MWH	T*MWH
1	1.4	1.4	419.9	0.015836		X								
1	1.3	1.3	422.9	0.015843			X							
2	5.6	5.5	278.6	0.015502									X	X
2	5.0	5.0	296.9	0.015545	X				X					
3	7.1	7.0	227.9	0.015379					X			X		X
3	6.5	6.4	248.6	0.015428	X								X	X
4	10.3	10.2	118.0	0.015111	X		X		X	X				
4	9.9	9.7	134.0	0.015150			X			X			X	X
5	12.1	11.9	59.3	0.014964	X	X	X		X		X			
5	10.8	10.6	104.0	0.015074	X		X		X	X		X		
6	12.5	12.4	46.1	0.014929	X	X	X		X		X	X		
6	12.5	12.3	47.8	0.014933	X	X	X		X	X	X			
7	13.4	13.2	18.3	0.014858	X	X	X		X		X	X	X	
7	13.3	13.1	21.3	0.014865	X	X	X		X		X	X		X
8	13.8	13.5	7.1	0.014827	X	X	X		X	X	X	X	X	
8	13.7	13.5	9.5	0.014833	X	X	X		X	X	X	X		X
9	13.8	13.5	9.0	0.014830	X	X	X	X	X	X	X	X	X	
9	13.8	13.5	9.1	0.014830	X	X	X		X	X	X	X	X	X
10	13.8	13.5	11.0	0.014832	X	X	X	X	X	X	X	X	X	X

Regression Analysis: RWH versus TWH, RHWH, RHWH1, MWH, TWH*MWH

The regression equation is

RWH = 0.0194 - 0.00129 TWH - 0.0522 RHWH + 0.0493 RHWH1 -0.000885 MWH
+0.000039 TWH*MWH

Predictor	Coef	SE Coef	T	P
Constant	0.019387	0.006451	3.01	0.003
TWH	-0.0012892	0.0002224	-5.80	0.000
RHWH	-0.05218	0.01415	-3.69	0.000
RHWH1	0.04926	0.01638	3.01	0.003
MWH	-0.0008847	0.0001371	-6.45	0.000
TWH*MWH	0.00003937	0.00000652	6.04	0.000

S = 0.01574   R-Sq = 2.7%   R-Sq(adj) = 2.6%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	5	0.0206556	0.0041311	16.67	0.000
Residual Error	2981	0.7386417	0.0002478		
Total	2986	0.7592973			

Source	DF	Seq SS
TWH	1	0.0002562
RHWH	1	0.0080655
RHWH1	1	0.0019430
MWH	1	0.0013563
TWH*MWH	1	0.0090346

Regression Analysis: RWH versus TWH, RHWH, MWH, TWH*MWH

The regression equation is
RWH = 0.0326 - 0.00126 TWH - 0.0100 RHWH -0.000870 MWH +0.000038 TWH*MWH

Predictor	Coef	SE Coef	T	P
Constant	0.032594	0.004732	6.89	0.000
TWH	-0.0012621	0.0002225	-5.67	0.000
RHWH	-0.009997	0.001892	-5.28	0.000
MWH	-0.0008697	0.0001372	-6.34	0.000
TWH*MWH	0.00003843	0.00000652	5.89	0.000

S = 0.01576 R-Sq = 2.4% R-Sq(adj) = 2.3%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	0.0184150	0.0046037	18.53	0.000
Residual Error	2982	0.7408823	0.0002485		
Total	2986	0.7592973			

Source	DF	Seq SS
TWH	1	0.0002562
RHWH	1	0.0080655
MWH	1	0.0014616
TWH*MWH	1	0.0086317

Regression Analysis: RWH versus T, RH, MWH, T*MWH

The regression equation is
RWH = 0.0196 -0.000726 T - 0.00723 RH -0.000530 MWH +0.000024 T*MWH

Predictor	Coef	SE Coef	T	P
Constant	0.019583	0.003164	6.19	0.000
T	-0.0007258	0.0001522	-4.77	0.000
RH	-0.007227	0.001375	-5.26	0.000
MWH	-0.00052994	0.00008919	-5.94	0.000
T*MWH	0.00002398	0.00000448	5.35	0.000

S = 0.01574 R-Sq = 2.7% R-Sq(adj) = 2.6%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	0.0204965	0.0051241	20.68	0.000
Residual Error	2982	0.7388008	0.0002478		
Total	2986	0.7592973			

Source	DF	Seq SS
T	1	0.0053895
RH	1	0.0063611
MWH	1	0.0016646
T*MWH	1	0.0070813

Regression Analysis: RWH versus T, RH, RH1, TWH, RHWH1, MWH

The regression equation is
RWH = 0.0127 + 0.00438 T - 0.0689 RH + 0.249 RH1 - 0.00449 TWH - 0.204 RHWH1 -0.000144 MWH

Predictor	Coef	SE Coef	T	P
Constant	0.012747	0.003159	4.04	0.000
T	0.0043805	0.0002304	19.02	0.000
RH	-0.068944	0.007817	-8.82	0.000
RH1	0.24918	0.01754	14.21	0.000
TWH	-0.0044867	0.0002347	-19.12	0.000
RHWH1	-0.20375	0.01346	-15.14	0.000
MWH	-0.00014439	0.00003730	-3.87	0.000

S = 0.01493 R-Sq = 12.5% R-Sq(adj) = 12.4%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	6	0.095125	0.015854	71.13	0.000
Residual Error	2980	0.664172	0.000223		
Total	2986	0.759297			

Source	DF	Seq SS
T	1	0.005389
RH	1	0.006361
RH1	1	0.000159
TWH	1	0.027564
RHWH1	1	0.052312
MWH	1	0.003339

Results for: WH SHAFT_1.MTW (WITHOUT THE OUTLIERS
Regression Analysis: RWH versus T, RH1, MWH, T*MWH

The regression equation is
RWH = 0.0215 -0.000712 T - 0.00845 RH1 -0.000524 MWH +0.000024 T*MWH

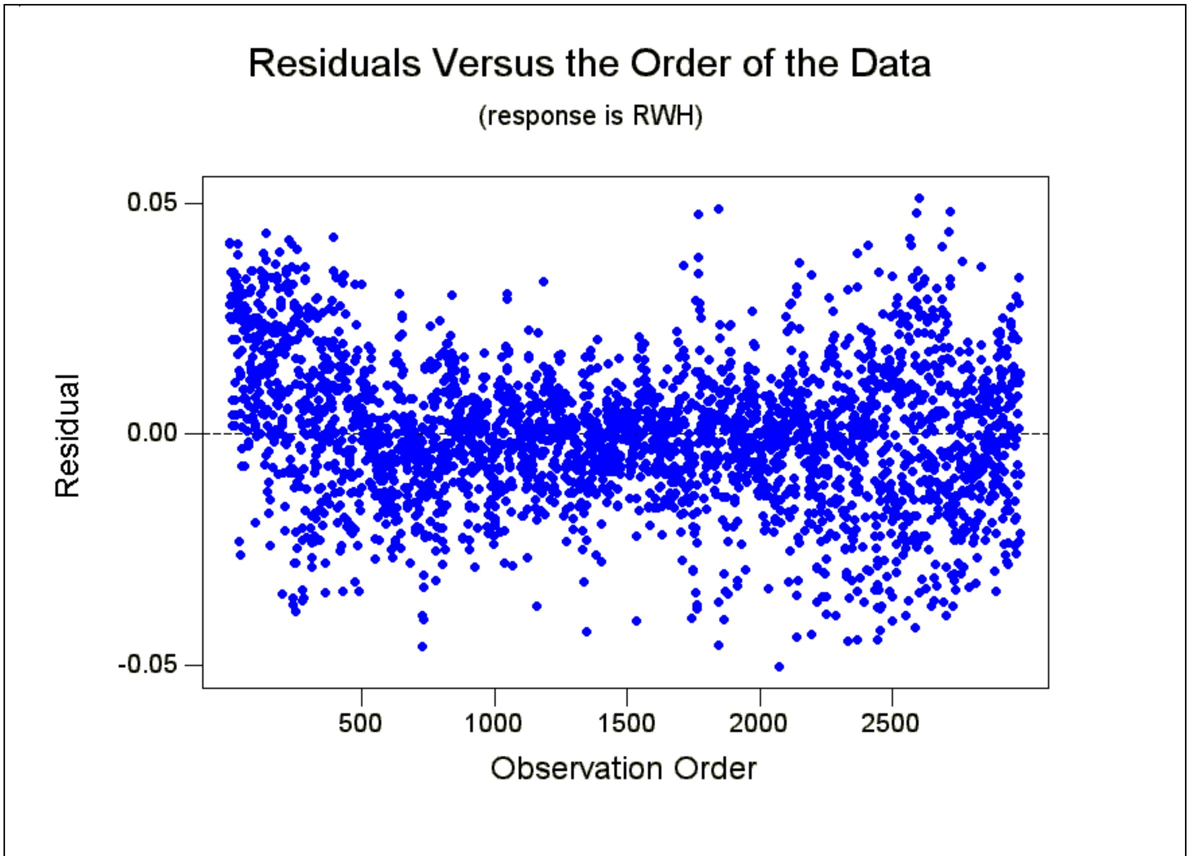
Predictor	Coef	SE Coef	T	P
Constant	0.021522	0.003324	6.47	0.000
T	-0.0007115	0.0001521	-4.68	0.000
RH1	-0.008453	0.001709	-4.94	0.000
MWH	-0.00052355	0.00008921	-5.87	0.000
T*MWH	0.00002365	0.00000449	5.27	0.000

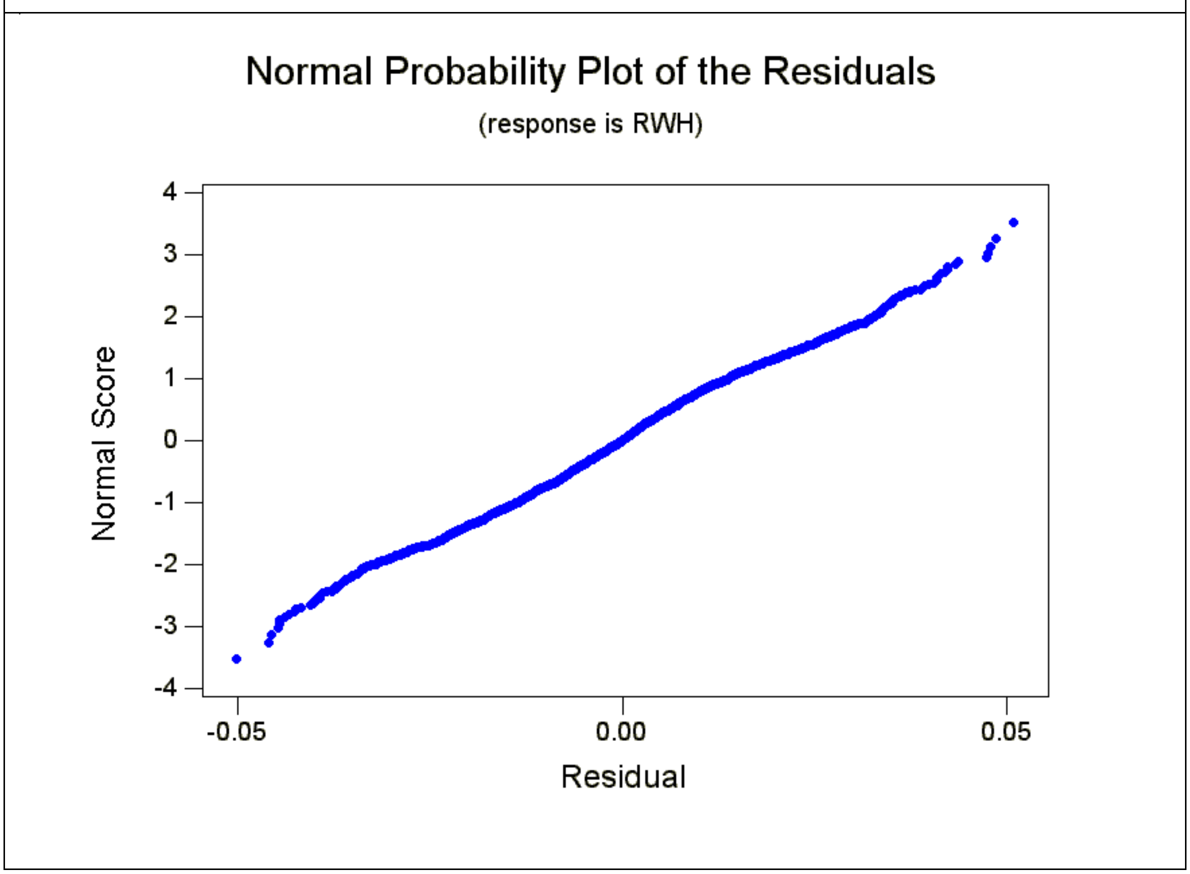
S = 0.01575 R-Sq = 2.6% R-Sq(adj) = 2.5%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	0.0197165	0.0049291	19.87	0.000
Residual Error	2982	0.7395808	0.0002480		
Total	2986	0.7592973			

Source	DF	Seq SS
T	1	0.0053895
RH1	1	0.0057837
MWH	1	0.0016581
T*MWH	1	0.0068853


Residuals Versus the Order of the Data
(response is RWH)
Residual
0.05
0.00
-0.05
500
1000
1500
2000
2500
Observation Order


Normal Probability Plot of the Residuals
(response is RWH)
Normal Score
4
3
2
1
0
-1
-2
-3
-4
-0.05
0.00
0.05
Residual

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Welcome to Minitab, press F1 for help.
Retrieving project from file: X:\WIPP\PsychroMpjFiles\UG workings\UG
Workings.MPJ
```

Results for: UG SHAFT.MTW

Best Subsets Regression: RUG versus T, RH, ...

Response is RUG

Vars	R-Sq	R-Sq(adj)	C-p	S	T	RH	RH1	BP	TUG	RHUG	RHUG1	BPUG	MUG	TUG*MUG
1	17.5	17.4	301.9	0.10708			X							
1	17.2	17.2	314.0	0.10726						X				
2	19.8	19.7	202.3	0.10558			X							X
2	19.0	19.0	234.3	0.10606		X								X
3	20.5	20.4	173.8	0.10514	X				X	X				
3	20.3	20.3	179.6	0.10523	X					X				X
4	21.3	21.2	138.4	0.10460	X				X	X				X
4	21.3	21.2	141.0	0.10464	X				X	X			X	
5	23.1	23.0	60.8	0.10340		X	X			X	X			X
5	22.3	22.2	96.4	0.10394	X	X	X			X	X			
6	23.3	23.2	54.2	0.10329		X	X	X		X	X			X
6	23.2	23.0	60.5	0.10338		X	X			X	X	X		X
7	24.4	24.2	10.7	0.10260		X	X	X		X	X	X		X
7	23.4	23.3	51.6	0.10323		X	X	X		X	X		X	X
8	24.5	24.3	7.6	0.10254		X	X	X	X	X	X	X		X
8	24.5	24.3	8.6	0.10255		X	X	X	X	X	X	X	X	
9	24.5	24.3	9.2	0.10255		X	X	X	X	X	X	X	X	X
9	24.5	24.3	9.5	0.10255	X	X	X	X	X	X	X	X		X
10	24.5	24.3	11.0	0.10256	X	X	X	X	X	X	X	X	X	X

Regression Analysis: RUG versus T, TUG, RHUG, TUG*MUG

The regression equation is
RUG = 0.182 + 0.00747 T - 0.00669 TUG - 0.314 RHUG -0.000016 TUG*MUG

Predictor	Coef	SE Coef	T	P
Constant	0.18239	0.01080	16.89	0.000
T	0.0074686	0.0006590	11.33	0.000
TUG	-0.006692	0.001038	-6.45	0.000
RHUG	-0.31406	0.01489	-21.09	0.000
TUG*MUG	-0.00001580	0.00000263	-6.00	0.000

S = 0.1046   R-Sq = 21.3%   R-Sq(adj) = 21.2%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	9.8688	2.4672	225.51	0.000
Residual Error	3329	36.4204	0.0109		
Total	3333	46.2891			

Source	DF	Seq SS
T	1	0.2770
TUG	1	4.6891
RHUG	1	4.5093
TUG*MUG	1	0.3934

Regression Analysis: RUG versus RH, RH1, BP, RHUG, RHUG1, BPUG, TUG*MUG

The regression equation is

RUG = - 1.87 + 1.07 RH - 1.83 RH1 + 0.133 BP - 2.40 RHUG + 2.79 RHUG1
- 0.104 BPUG -0.000023 TUG*MUG

Predictor	Coef	SE Coef	T	P
Constant	-1.8732	0.3555	-5.27	0.000
RH	1.07230	0.08897	12.05	0.000
RH1	-1.8319	0.1253	-14.62	0.000
BP	0.13297	0.01848	7.20	0.000
RHUG	-2.3999	0.1853	-12.95	0.000
RHUG1	2.7936	0.2102	13.29	0.000
BPUG	-0.10390	0.01541	-6.74	0.000
TUG*MUG	-0.00002309	0.00000221	-10.45	0.000

S = 0.1026 R-Sq = 24.4% R-Sq(adj) = 24.2%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	7	11.2756	1.6108	153.01	0.000
Residual Error	3326	35.0135	0.0105		
Total	3333	46.2891			

Source	DF	Seq SS
RH	1	7.7698
RH1	1	0.3282
BP	1	0.5777
RHUG	1	0.1251
RHUG1	1	1.3032
BPUG	1	0.0214
TUG*MUG	1	1.1503

Regression Analysis: RUG versus RH, RH1, RHUG, RHUG1, TUG*MUG

The regression equation is

RUG = - 0.0537 + 0.899 RH - 1.51 RH1 - 2.15 RHUG + 2.44 RHUG1 -0.000013 TUG*MUG

Predictor	Coef	SE Coef	T	P
Constant	-0.05366	0.03060	-1.75	0.080
RH	0.89919	0.08560	10.50	0.000
RH1	-1.5066	0.1169	-12.88	0.000
RHUG	-2.1454	0.1805	-11.88	0.000
RHUG1	2.4356	0.2029	12.00	0.000
TUG*MUG	-0.00001348	0.00000143	-9.44	0.000

```
S = 0.1034      R-Sq = 23.1%     R-Sq(adj) = 23.0%

Analysis of Variance

Source            DF        SS        MS        F       P
Regression         5   10.7063    2.1413   200.27   0.000
Residual Error  3328   35.5829    0.0107
Total           3333   46.2891

Source       DF     Seq SS
RH            1     7.7698
RH1           1     0.3282
RHUG          1     0.2994
RHUG1         1     1.3561
TUG*MUG       1     0.9528
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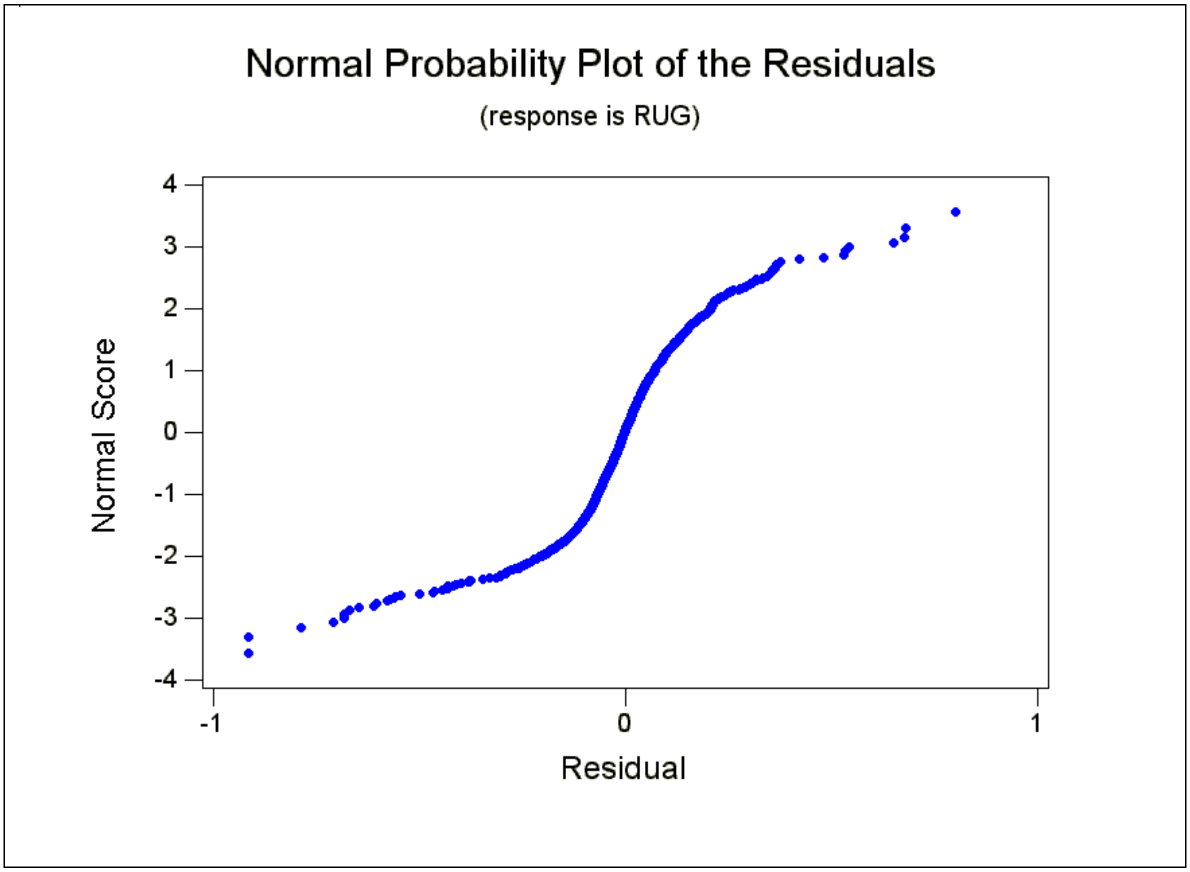

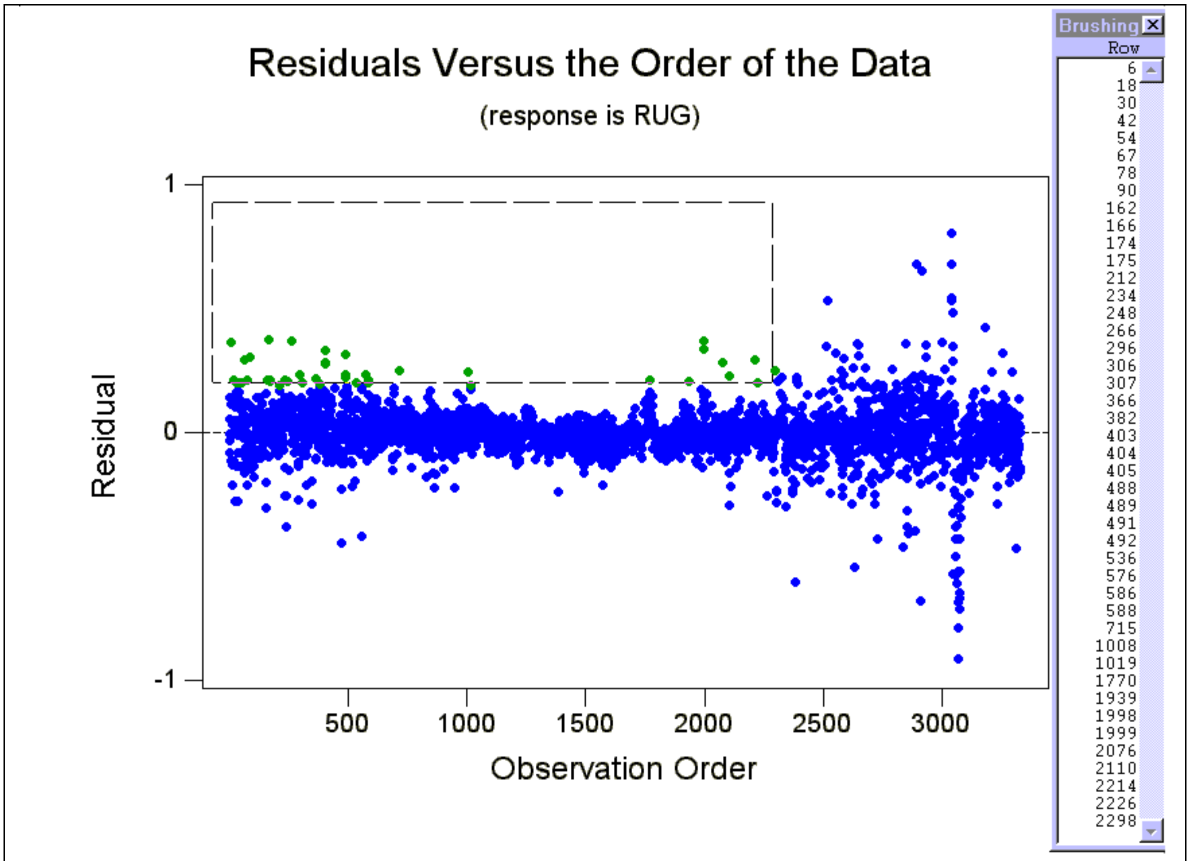
Residuals Versus the Order of the Data
(response is RUG)
Residual
1
0
-1
500
1000
1500
2000
2500
3000
Observation Order
Brushing
Row
6
18
30
42
54
67
78
90
162
166
174
175
212
234
248
266
296
306
307
366
382
403
404
405
488
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2110
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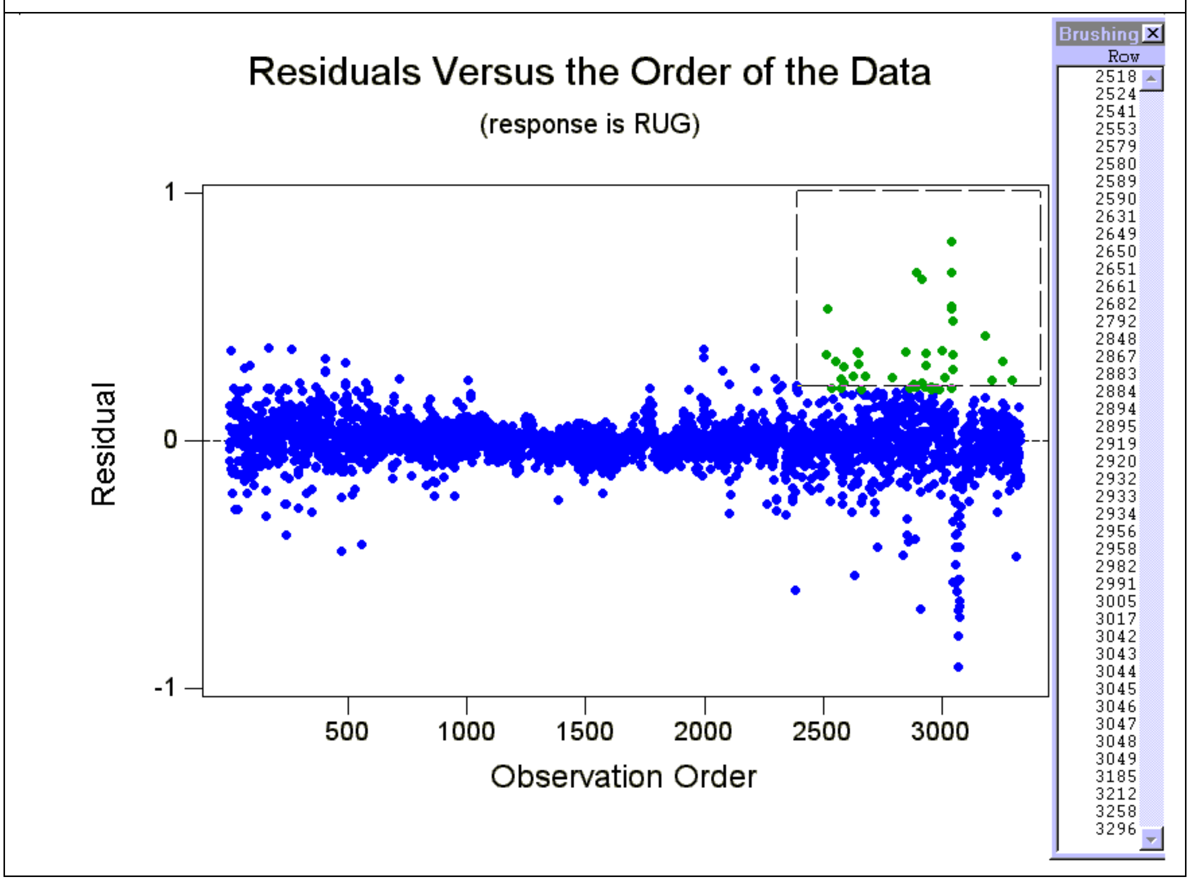
2226
2298


Residuals Versus the Order of the Data
(response is RUG)
Residual
1
0
-1
500
1000
1500
2000
2500
3000
Observation Order
Brushing
Row
2518
2524
2541
2553
2579
2580
2589
2590
2631
2649
2650
2651
2661
2682
2792
2848
2867
2883
2884
2894
2895
2919
2920
2932
2933
2934
2956
2958
2982
2991
3005
3017
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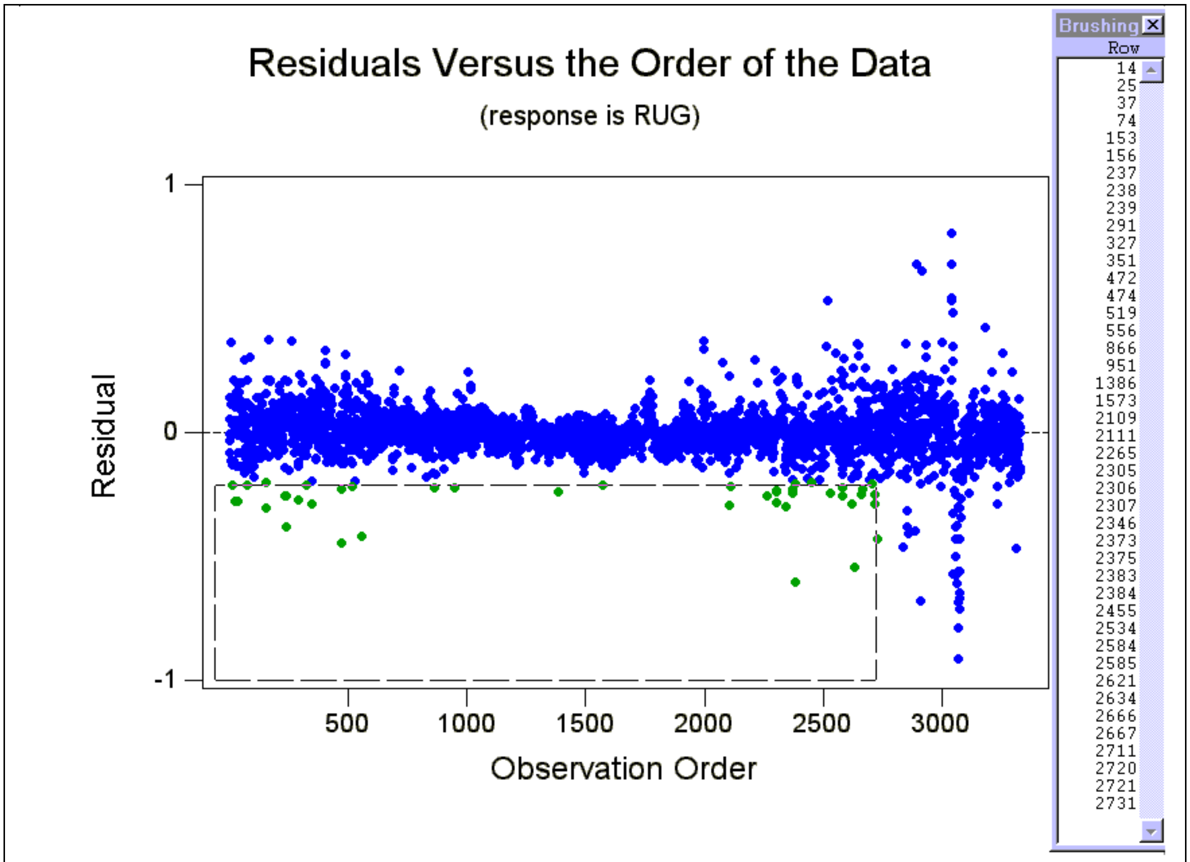
3185
3212
3258
3296


Residuals Versus the Order of the Data
(response is RUG)
Residual
1
0
-1
500
1000
1500
2000
2500
3000
Observation Order
Brushing
Row
14
25
37
74
153
156
237
238
239
291
327
351
472
474
519
556
866
951
1386
1573
2109
2111
2265
2305
2306
2307
2346
2373
2375
2383
2384
2455
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2585
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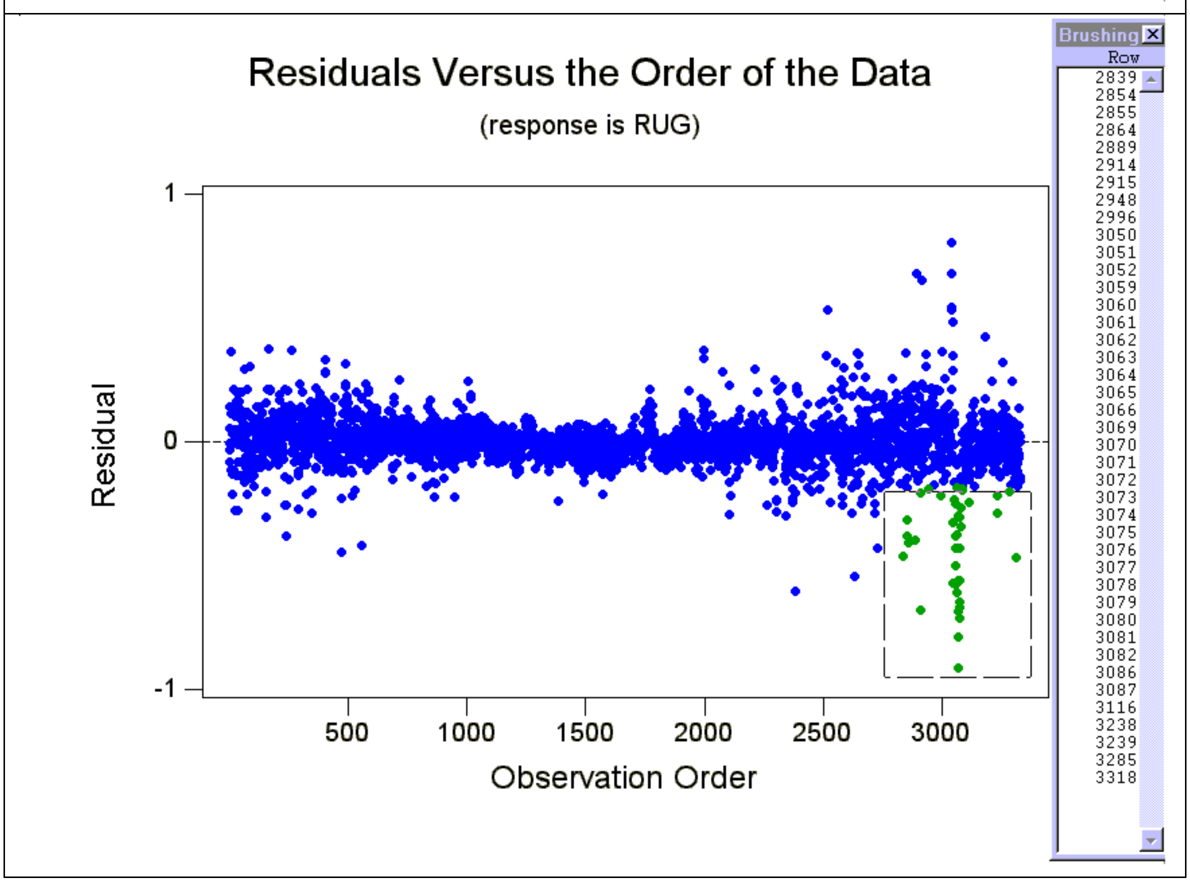
2711
2720
2721
2731


Residuals Versus the Order of the Data
(response is RUG)
Residual
1
0
-1
500
1000
1500
2000
2500
3000
Observation Order
Brushing
Row
2839
2854
2855
2864
2889
2914
2915
2948
2996
3050
3051
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3086
3087
3116
3238
3239
3285
3318

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Welcome to Minitab, press F1 for help.
Retrieving project from file: X:\WIPP\PsychroMpjFiles\UG workings\UG
Workings.MPJ
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Results for: UG SHAFT_1.MTW (WITHOUT THE OUTLIERS

Best Subsets Regression: RUG versus TUG, RHUG, RHUG1, BPUG, MUG, TUG*MUG

```
Response is RUG

                                                            T
                                                            U
                                                        R   G
                                                      R H B *
                                                    T H U P M M
                                                    U U G U U U
Vars   R-Sq    R-Sq(adj)         C-p          S     G G 1 G G G

   1   18.0         18.0        71.4   0.060754       X
   1   18.0         18.0        72.4   0.060764         X
   2   19.2         19.2        28.1   0.060318       X     X
   2   19.1         19.1        32.1   0.060357         X   X
   3   19.8         19.7         8.2   0.060111       X   X X
   3   19.8         19.7         8.7   0.060116         X X X
   4   19.9         19.8         6.6   0.060085     X   X X X
   4   19.9         19.8         6.6   0.060085     X X   X X
   5   20.0         19.9         5.0   0.060059     X X X X X
   5   20.0         19.9         5.1   0.060060       X X X X X
   6   20.0         19.8         7.0   0.060069     X X X X X X
```

Best Subsets Regression: RUG versus T, RH, ...

Response is RUG

Vars	R-Sq	R-Sq(adj)	C-p	S	T	RH	RH1	BP	TUG	RHUG	RHUG1	BPUG	MUG	TUG*MUG
1	21.2	21.2	142.1	0.059569			X							
1	20.1	20.1	186.0	0.059980		X								
2	22.8	22.8	79.4	0.058966			X							X
2	22.4	22.3	97.4	0.059137			X					X		
3	23.5	23.4	54.8	0.058722	X		X							X
3	23.4	23.3	59.0	0.058763	X				X	X				
4	24.3	24.2	24.9	0.058427	X				X	X			X	
4	24.2	24.1	26.1	0.058437	X				X	X				X
5	24.6	24.5	14.4	0.058316	X			X	X	X			X	
5	24.5	24.4	16.3	0.058334	X			X	X	X				X
6	24.7	24.5	13.0	0.058293	X			X	X	X		X	X	
6	24.6	24.5	14.4	0.058306	X	X		X	X	X			X	
7	24.7	24.6	12.2	0.058275	X	X		X	X	X		X	X	
7	24.7	24.5	12.9	0.058282		X	X	X		X	X	X		X
8	24.8	24.6	11.8	0.058262	X	X	X	X	X	X	X		X	
8	24.8	24.6	12.3	0.058267	X	X	X	X	X	X		X	X	
9	24.9	24.7	9.1	0.058226	X	X	X	X	X	X	X	X	X	
9	24.9	24.6	10.7	0.058242	X	X	X	X	X	X	X	X		X
10	24.9	24.7	11.0	0.058235	X	X	X	X	X	X	X	X	X	X

Regression Analysis: RUG versus T, TUG, RHUG, TUG*MUG

The regression equation is
RUG = 0.104 + 0.00550 T - 0.00496 TUG - 0.182 RHUG -0.000009 TUG*MUG

Predictor	Coef	SE Coef	T	P
Constant	0.103808	0.006409	16.20	0.000
T	0.0054994	0.0003890	14.14	0.000
TUG	-0.0049648	0.0006079	-8.17	0.000
RHUG	-0.181689	0.008839	-20.56	0.000
TUG*MUG	-0.00000909	0.00000154	-5.89	0.000

S = 0.05844   R-Sq = 24.2%   R-Sq(adj) = 24.1%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	3.29915	0.82479	241.52	0.000
Residual Error	3020	10.31307	0.00341		
Total	3024	13.61222			

Source	DF	Seq SS
T	1	0.26053
TUG	1	1.58861
RHUG	1	1.33137
TUG*MUG	1	0.11863

Regression Analysis: RUG versus TUG, RHUG1, TUG*MUG

The regression equation is
RUG = 0.107 + 0.00218 TUG - 0.238 RHUG1 -0.000010 TUG*MUG

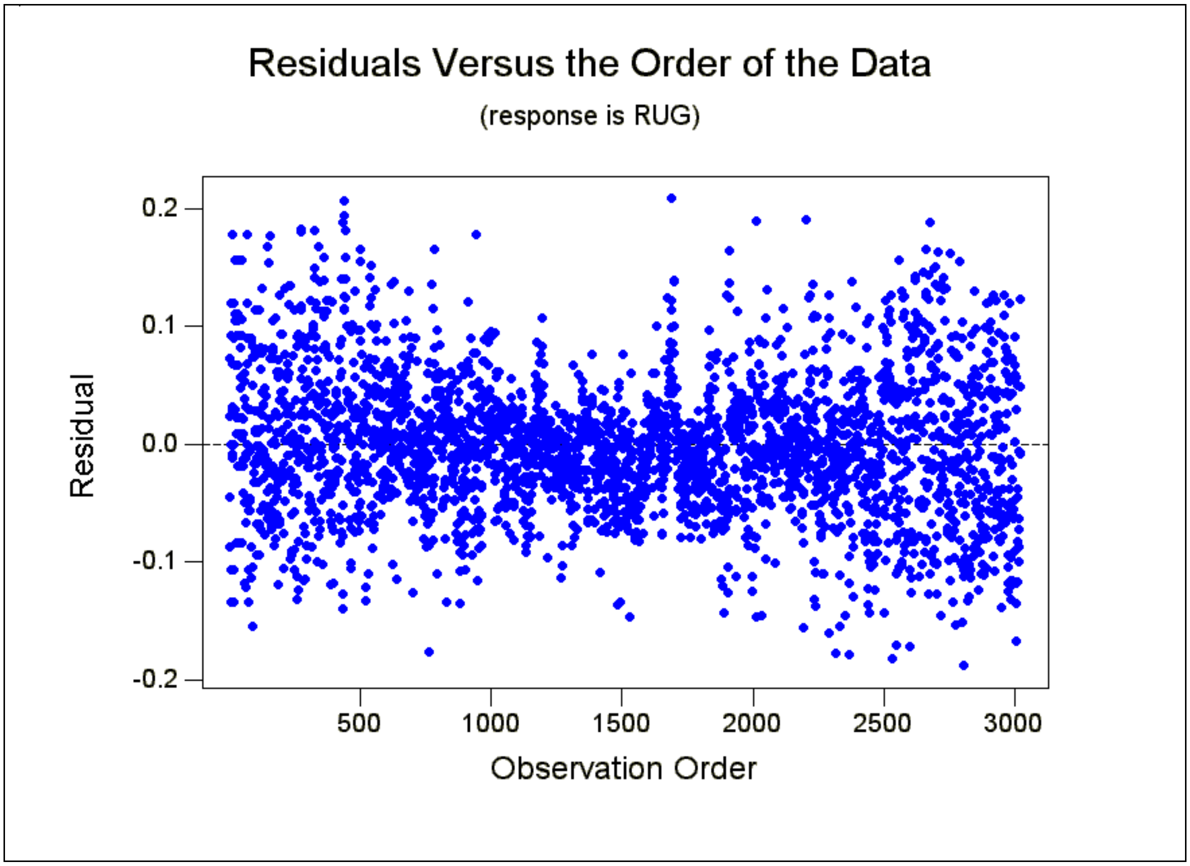
Predictor	Coef	SE Coef	T	P
Constant	0.106660	0.006623	16.10	0.000
TUG	0.0021767	0.0003427	6.35	0.000
RHUG1	-0.238123	0.008914	-26.71	0.000
TUG*MUG	-0.00001013	0.00000159	-6.38	0.000

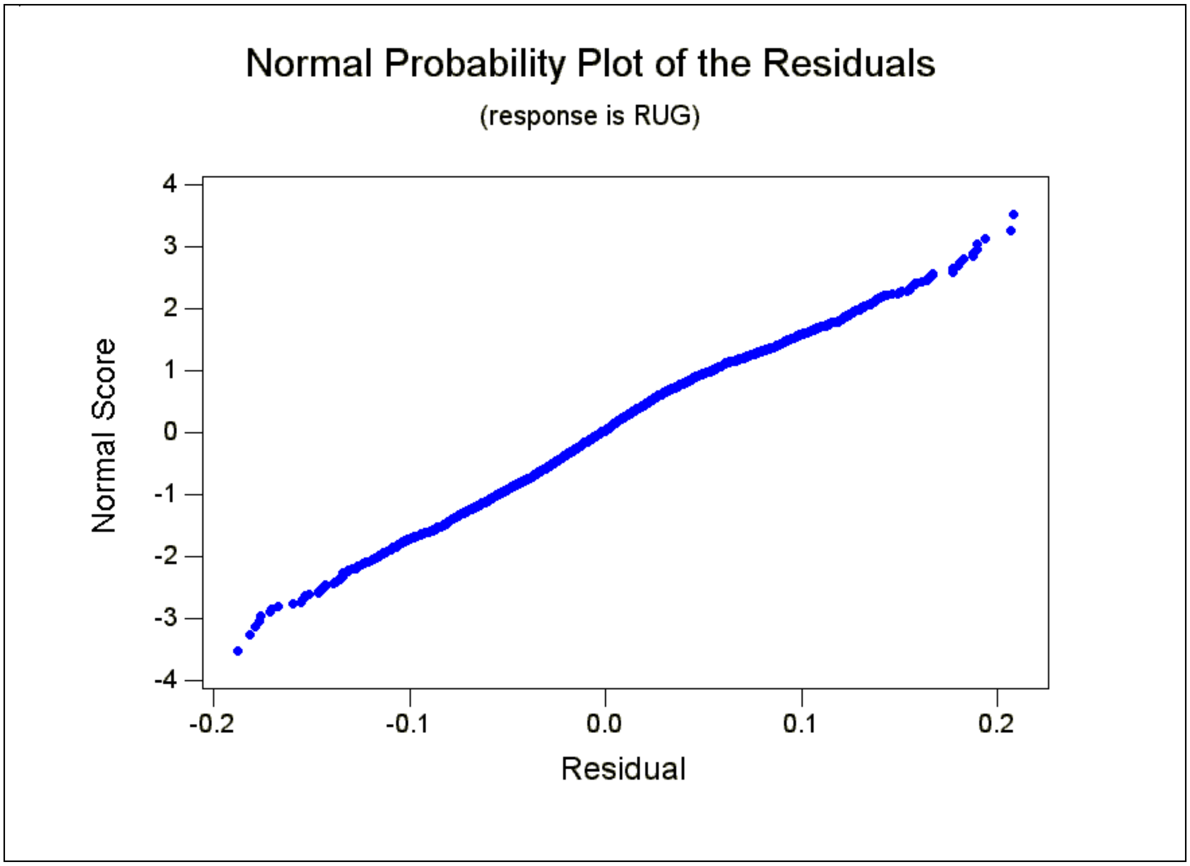
S = 0.06036   R-Sq = 19.2%   R-Sq(adj) = 19.1%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	2.60722	0.86907	238.57	0.000
Residual Error	3021	11.00500	0.00364		
Total	3024	13.61222			

Source	DF	Seq SS
TUG	1	0.00580
RHUG1	1	2.45335
TUG*MUG	1	0.14808




Normal Probability Plot of the Residuals
(response is RUG)
Normal Score
4
3
2
1
0
-1
-2
-3
-4
-0.2
-0.1
0.0
0.1
0.2
Residual

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Retrieving project from file: X:\WIPP\PsychroMpjFiles\ES shaft\ES SHAFT.MPJ

Results for: ES SHAFT.MTW

Best Subsets Regression: RES versus TES, RHES, RHES1, BPES, MES, MES/TES

Response is RES

Vars	R-Sq	R-Sq(adj)	C-p	S	TES	RHES	RHES1	BPES	MES	MES/TES
1	6.3	6.3	62.5	0.11398		X				
1	6.2	6.2	64.3	0.11400			X			
2	7.0	7.0	37.4	0.11354		X			X	
2	6.9	6.9	41.0	0.11360			X		X	
3	7.5	7.5	21.2	0.11325	X	X				X
3	7.5	7.4	22.8	0.11327	X	X			X	
4	8.1	8.0	3.7	0.11293	X	X		X		X
4	8.1	7.9	4.9	0.11295	X	X		X	X	
5	8.1	8.0	5.0	0.11294	X	X	X	X		X
5	8.1	7.9	5.7	0.11295	X	X		X	X	X
6	8.1	7.9	7.0	0.11295	X	X	X	X	X	X

Regression Analysis: RES versus TES, RHES1, MES/TES

The regression equation is
RES = 0.439 - 0.00848 TES - 0.207 RHES1 - 0.0122 MES/TES

Predictor	Coef	SE Coef	T	P
Constant	0.43942	0.05031	8.73	0.000
TES	-0.008480	0.001395	-6.08	0.000
RHES1	-0.20664	0.02006	-10.30	0.000
MES/TES	-0.012192	0.002069	-5.89	0.000

S = 0.1133   R-Sq = 7.4%   R-Sq(adj) = 7.4%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	3.4341	1.1447	89.15	0.000
Residual Error	3330	42.7583	0.0128		
Total	3333	46.1924			

Source	DF	Seq SS
TES	1	1.8277
RHES1	1	1.1605
MES/TES	1	0.4459

Regression Analysis: RES versus TES, RHES, BPES, MES/TES

The regression equation is
RES = 1.76 - 0.0106 TES - 0.197 RHES - 0.0137 BPES - 0.0130 MES/TES

Predictor	Coef	SE Coef	T	P
Constant	1.7578	0.3117	5.64	0.000
TES	-0.010575	0.001448	-7.30	0.000
RHES	-0.19744	0.01955	-10.10	0.000
BPES	-0.013671	0.003094	-4.42	0.000
MES/TES	-0.013002	0.002069	-6.28	0.000

S = 0.1129   R-Sq = 8.1%   R-Sq(adj) = 8.0%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	3.73514	0.93378	73.22	0.000
Residual Error	3329	42.45727	0.01275		
Total	3333	46.19241			

Source	DF	Seq SS
TES	1	1.82768
RHES	1	1.18695
BPES	1	0.21692
MES/TES	1	0.50360

Regression Analysis: RES versus TES, RHES, MES/TES

The regression equation is
RES = 0.399 - 0.00865 TES - 0.205 RHES - 0.0126 MES/TES

Predictor	Coef	SE Coef	T	P
Constant	0.39866	0.05049	7.90	0.000
TES	-0.008649	0.001385	-6.25	0.000
RHES	-0.20502	0.01953	-10.50	0.000
MES/TES	-0.012566	0.002072	-6.06	0.000

S = 0.1132   R-Sq = 7.5%   R-Sq(adj) = 7.5%

Analysis of Variance

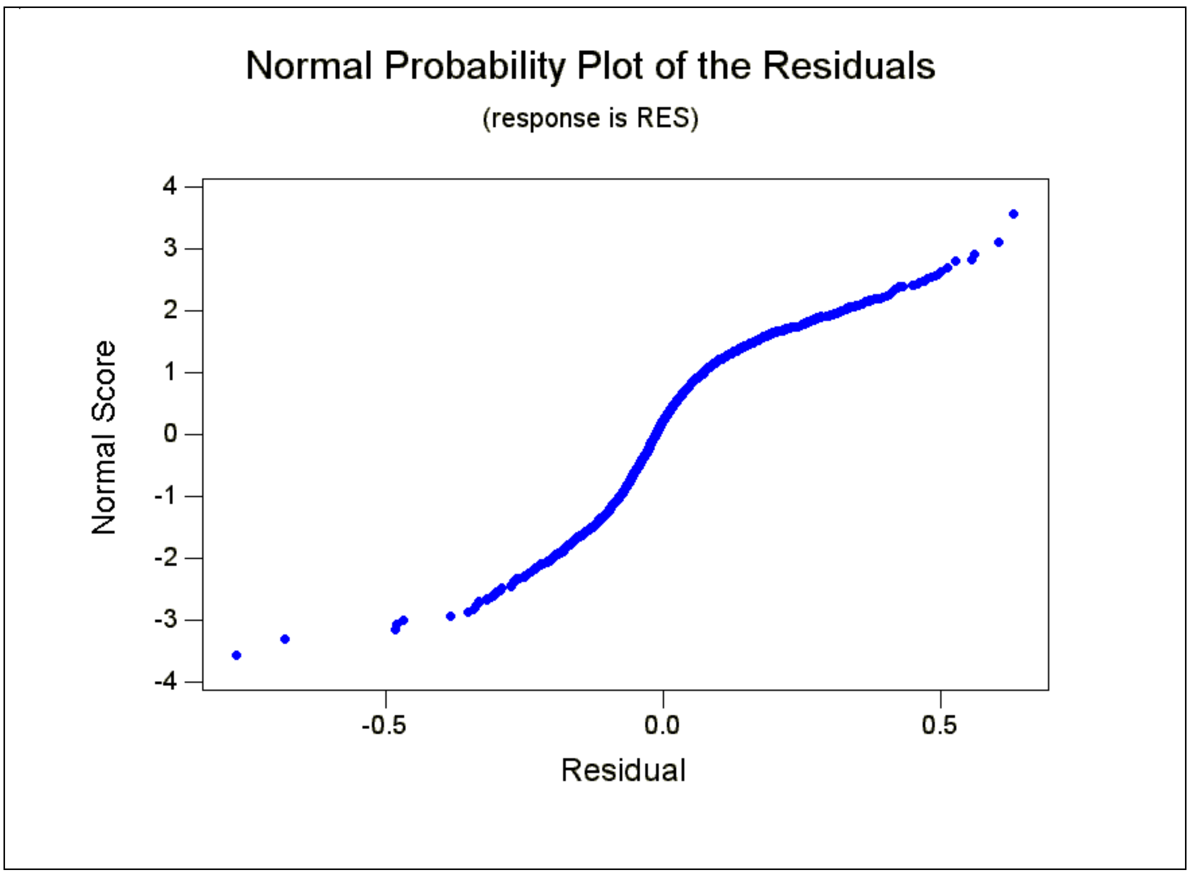
Source	DF	SS	MS	F	P
Regression	3	3.4861	1.1620	90.61	0.000
Residual Error	3330	42.7063	0.0128		
Total	3333	46.1924			

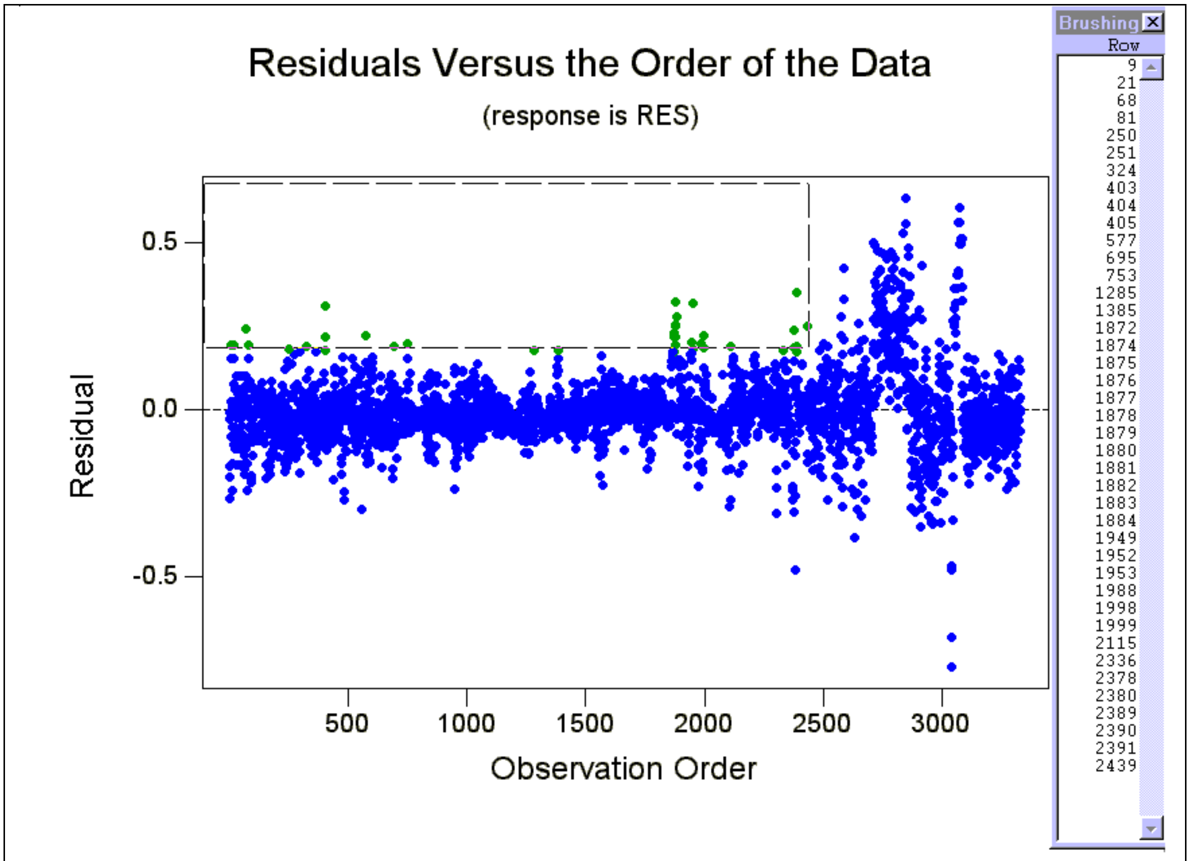
Source	DF	Seq SS
TES	1	1.8277
RHES	1	1.1869
MES/TES	1	0.4715

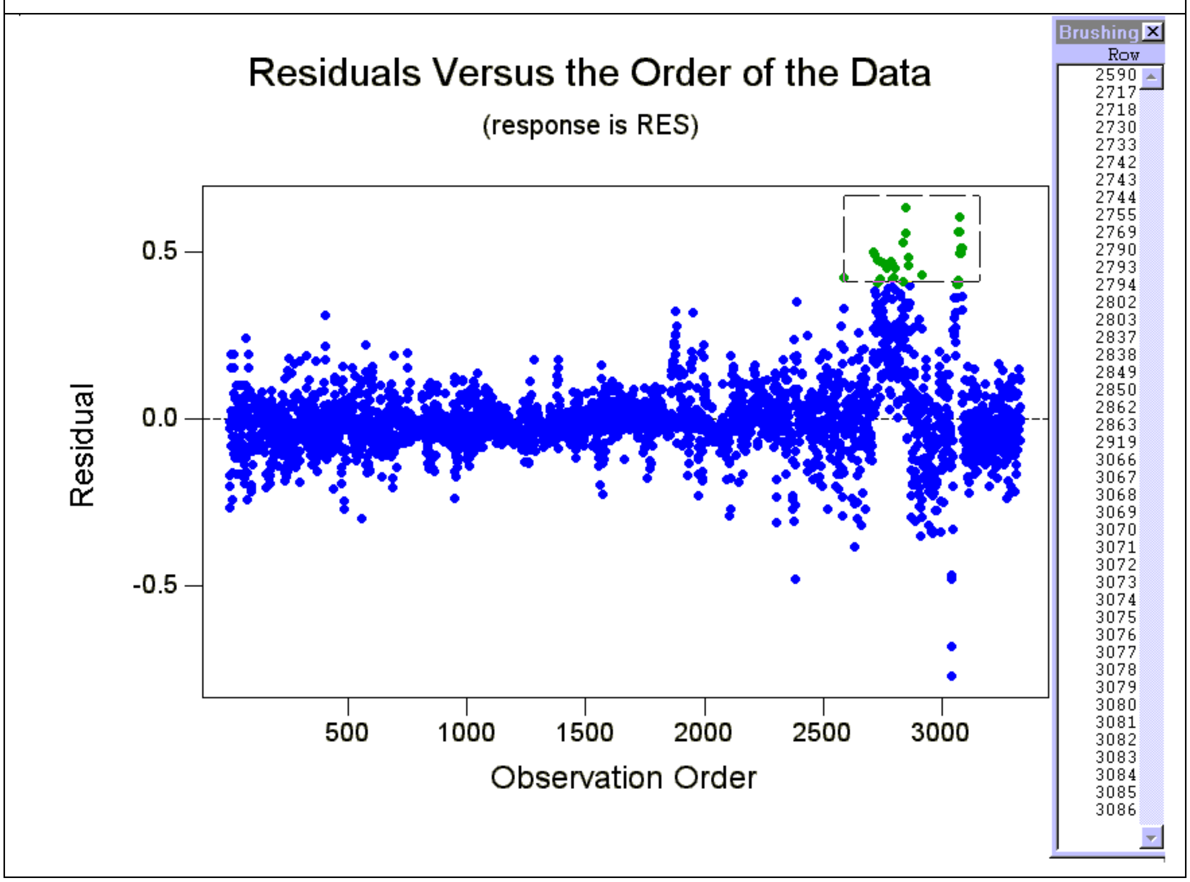
Regression Analysis: RES versus TES, RHES1, MES/TES

The regression equation is

```
RES = 0.439 - 0.00848 TES - 0.207 RHES1 - 0.0122 MES/TES

Predictor          Coef      SE Coef          T        P
Constant        0.43942      0.05031       8.73    0.000
TES           -0.008480     0.001395      -6.08    0.000
RHES1          -0.20664      0.02006     -10.30    0.000
MES/TES       -0.012192     0.002069      -5.89    0.000

S = 0.1133      R-Sq = 7.4%      R-Sq(adj) = 7.4%

Analysis of Variance

Source             DF          SS          MS         F        P
Regression          3      3.4341      1.1447     89.15    0.000
Residual Error   3330     42.7583      0.0128
Total            3333     46.1924

Source        DF      Seq SS
TES            1      1.8277
RHES1          1      1.1605
MES/TES        1      0.4459
```




Residuals Versus the Order of the Data
(response is RES)
Residual
0.5
0.0
-0.5
500
1000
1500
2000
2500
3000
Observation Order
Brushing
Row
9
21
68
81
250
251
324
403
404
405
577
695
753
1285
1385
1872
1874
1875
1876
1877
1878
1879
1880
1881
1882
1883
1884
1949
1952
1953
1988
1998
1999
2115
2336
2378
2380
2389
2390
2391
2439


Residuals Versus the Order of the Data
(response is RES)
Residual
0.5
0.0
-0.5
500
1000
1500
2000
2500
3000
Observation Order
Brushing
Row
2590
2717
2718
2730
2733
2742
2743
2744
2755
2769
2790
2793
2794
2802
2803
2837
2838
2849
2850
2862
2863
2919
3066
3067
3068
3069
3070
3071
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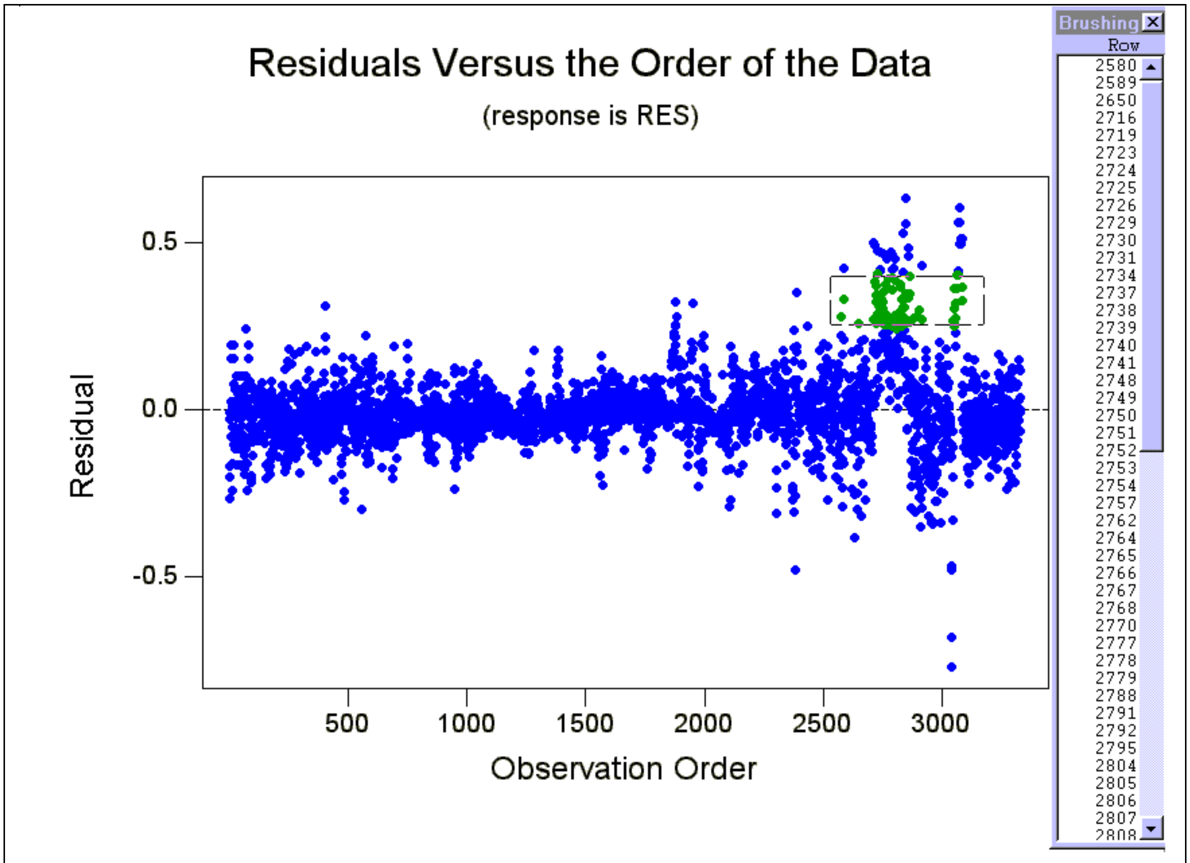
3083
3084
3085
3086


Residuals Versus the Order of the Data
(response is RES)
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0.0
-0.5
500
1000
1500
2000
2500
3000
Observation Order
Brushing
Row
2580
2589
2650
2716
2719
2723
2724
2725
2726
2729
2730
2731
2734
2737
2738
2739
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2748
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2751
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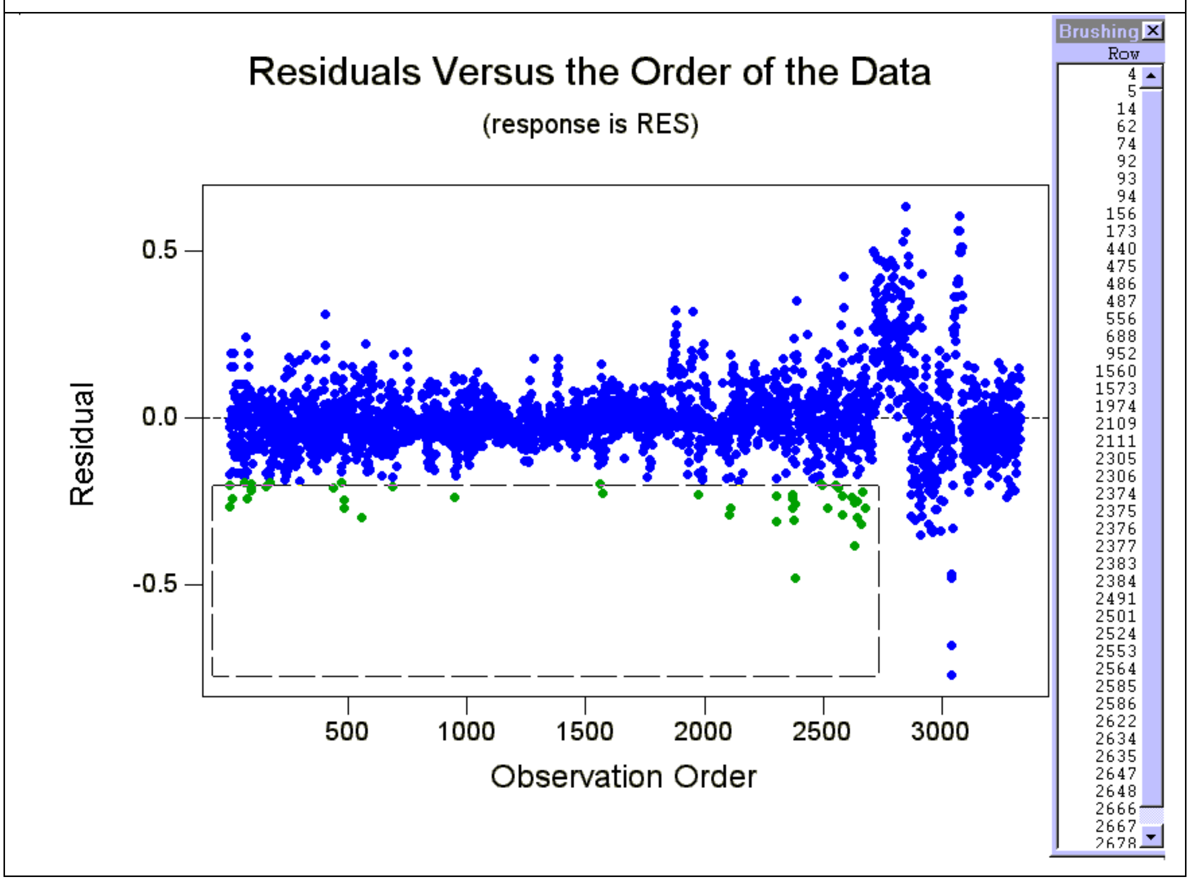
2807


Residuals Versus the Order of the Data
(response is RES)
Residual
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0.0
-0.5
500
1000
1500
2000
2500
3000
Observation Order
Brushing
Row
4
5
14
62
74
92
93
94
156
173
440
475
486
487
556
688
952
1560
1573
1974
2109
2111
2305
2306
2374
2375
2376
2377
2383
2384
2491
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2524
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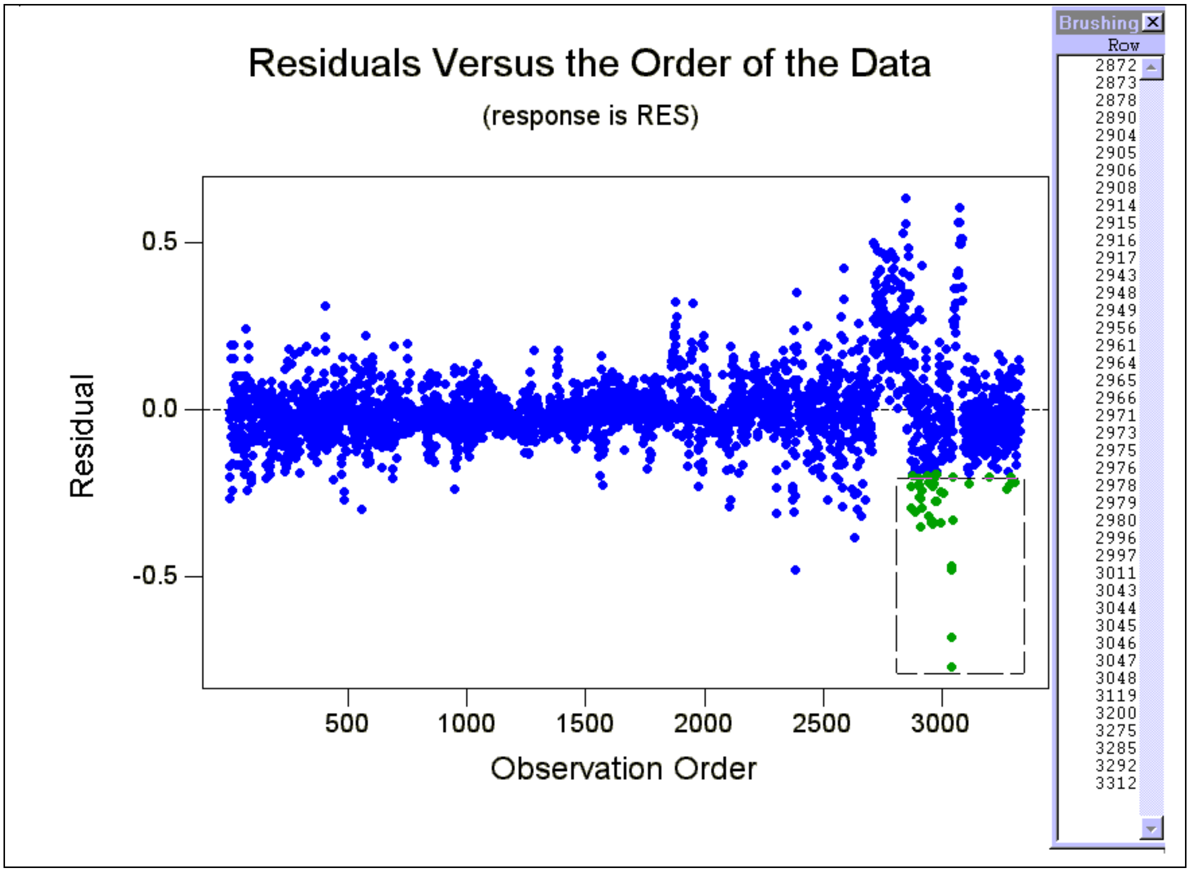
2667


Residuals Versus the Order of the Data
(response is RES)
Residual
0.5
0.0
-0.5
500
1000
1500
2000
2500
3000
Observation Order
Brushing
Row
2872
2873
2878
2890
2904
2905
2906
2908
2914
2915
2916
2917
2943
2948
2949
2956
2961
2964
2965
2966
2971
2973
2975
2976
2978
2979
2980
2996
2997
3011
3043
3044
3045
3046
3047
3048
3119
3200
3275
3285
3292
3312

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Welcome to Minitab, press F1 for help.
Retrieving project from file: X:\WIPP\PSYCHR~3\ESSHAF~1\ESSHAF~1.MPJ

Results for: ES SHAFT_1.MTW (WITHOUT THE OUTLIERS

Best Subsets Regression: RES versus TES, RHES, RHES1, BPES, MES, MES/TES

Response is RES

Vars	R-Sq	R-Sq(adj)	C-p	S	TES	RHES	RHES1	BPES	MES	MES/TES
1	16.2	16.2	103.0	0.069419			X			
1	15.9	15.9	114.3	0.069545		X				
2	17.5	17.5	55.7	0.068883	X		X			
2	17.3	17.3	63.7	0.068972	X	X				
3	18.6	18.6	16.1	0.068428	X		X			X
3	18.6	18.5	17.2	0.068441	X		X		X	
4	19.0	18.9	3.2	0.068273	X		X	X		X
4	19.0	18.9	4.1	0.068283	X		X	X	X	
5	19.0	18.9	5.0	0.068281	X	X	X	X		X
5	19.0	18.9	5.2	0.068284	X		X	X	X	X
6	19.0	18.9	7.0	0.068293	X	X	X	X	X	X

Regression Analysis: RES versus TES, RHES1, BPES, MES/TES

The regression equation is
RES = 1.13 - 0.00929 TES - 0.192 RHES1 - 0.00753 BPES - 0.00839 MES/TES

Predictor	Coef	SE Coef	T	P
Constant	1.1323	0.1960	5.78	0.000
TES	-0.0092909	0.0009063	-10.25	0.000
RHES1	-0.19246	0.01319	-14.60	0.000
BPES	-0.007532	0.001956	-3.85	0.000
MES/TES	-0.008386	0.001280	-6.55	0.000

S = 0.06827   R-Sq = 19.0%   R-Sq(adj) = 18.9%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	3.32163	0.83041	178.15	0.000
Residual Error	3032	14.13265	0.00466		
Total	3036	17.45429			

Source	DF	Seq SS
TES	1	2.08283
RHES1	1	0.97534
BPES	1	0.06348
MES/TES	1	0.19999

Regression Analysis: RES versus TES, RHES1, MES/TES

The regression equation is
RES = 0.387 - 0.00825 TES - 0.199 RHES1 - 0.00826 MES/TES

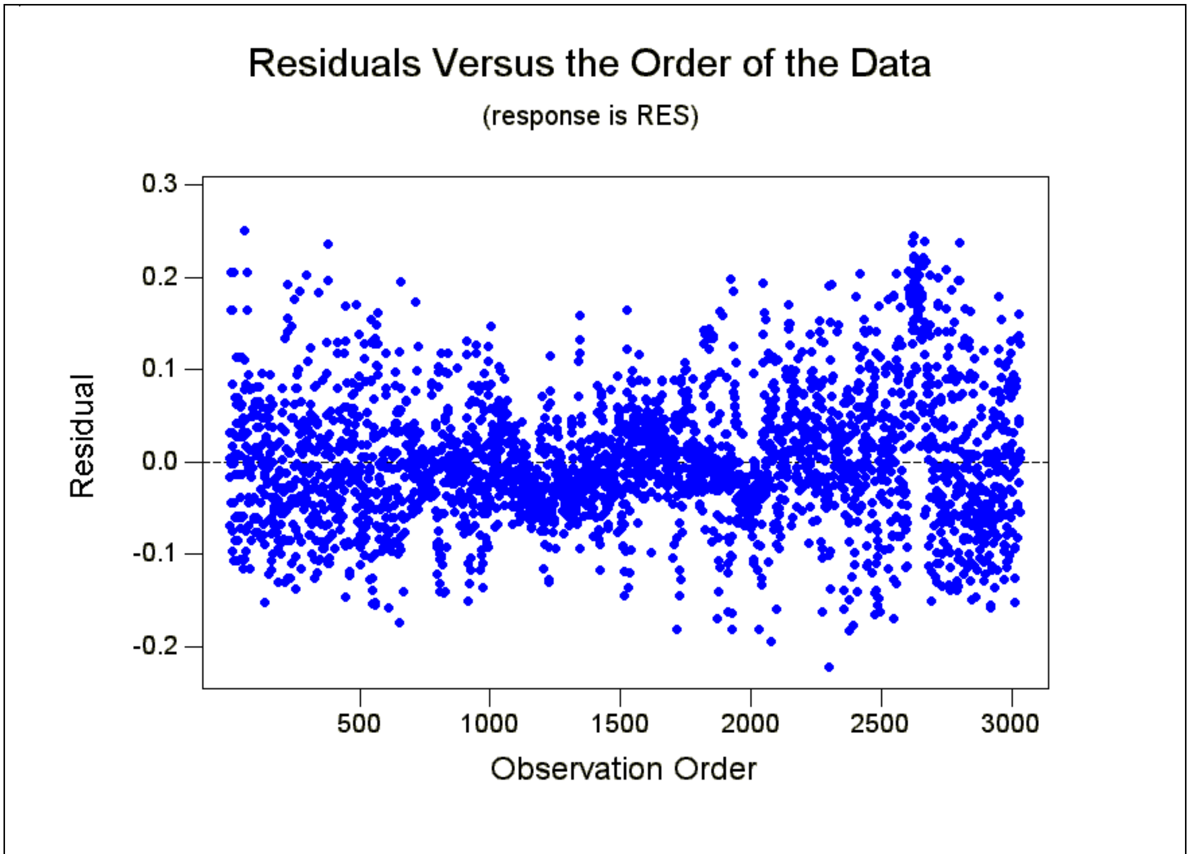
Predictor	Coef	SE Coef	T	P
Constant	0.38704	0.03127	12.38	0.000
TES	-0.0082453	0.0008666	-9.51	0.000
RHES1	-0.19931	0.01310	-15.22	0.000
MES/TES	-0.008264	0.001283	-6.44	0.000

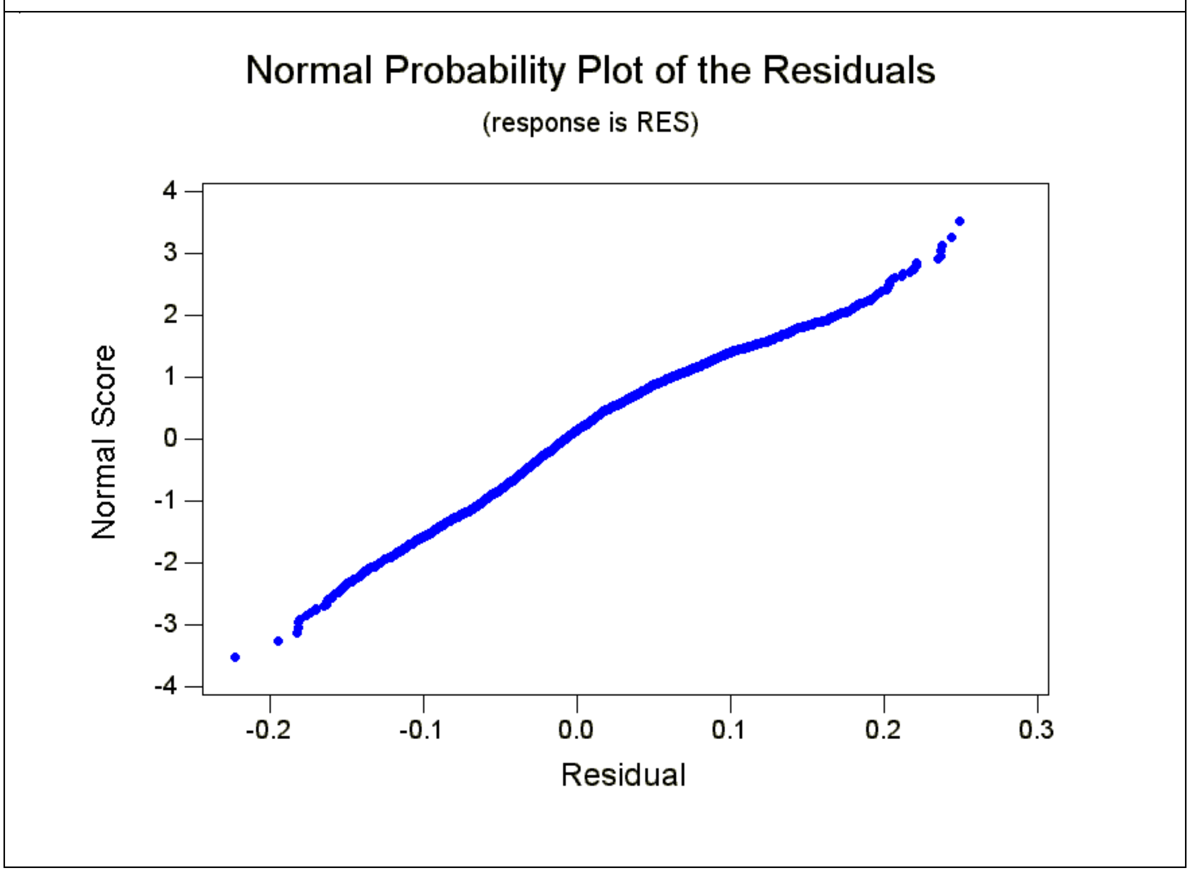
S = 0.06843   R-Sq = 18.6%   R-Sq(adj) = 18.6%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	3.2525	1.0842	231.54	0.000
Residual Error	3033	14.2018	0.0047		
Total	3036	17.4543			

Source	DF	Seq SS
TES	1	2.0828
RHES1	1	0.9753
MES/TES	1	0.1943


Residuals Versus the Order of the Data
(response is RES)
Residual
0.3
0.2
0.1
0.0
-0.1
-0.2
500
1000
1500
2000
2500
3000
Observation Order


Normal Probability Plot of the Residuals
(response is RES)
Normal Score
4
3
2
1
0
-1
-2
-3
-4
-0.2
-0.1
0.0
0.1
0.2
0.3
Residual