SALT BALANCE IN THE RIO GRANDE PROJECT FROM SAN MARCIAL, NEW MEXICO TO FORT QUITMAN, TEXAS

BY

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A Thesis submitted to the Graduate School

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ABSTRACT

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Using historical data, the purpose of this study was to determine the occurrence and distribution both temporally and spatially of salt in the Rio Grande within the Rio Grande Project (RGP) in New Mexico and west Texas. The concentration in the river of total dissolved solids (TDS), major ions, and flow were analyzed generally on a monthly time step for river metering stations at San Marcial, below Elephant Butte Dam, below Caballo Dam, at Leasburg Dam, and below Mesilla Dam (all in New Mexico), and at El Paso and Fort Quitman, Texas. In addition, time series models have been constructed that may assist in better understanding the behavior of the system and also be used for forecasting purposes.

Monthly flow data for various gaging stations from 1934 to the present are available. However, continuous monthly water quality data in terms of total dissolved solids (TDS) and the major ions were acquired by the participating government agencies only for the 30-year period from 1934 to 1963. For the purposes of this study, there were no useable water quality data available for the period between 1963 and 1980.

Between 1980 and 1994, monthly water quality data in terms of TDS is mostly complete, with some gaps. Ion data is largely non-existent for the period since 1963 except for El Paso and Ft. Quitman. For the purposes of this study, the values of the major ions for the period between 1980 and 1994 were estimated based on a determination of an average fraction of TDS compiled from the 1934-1963 data. During the 30 years between 1934 and 1963 monthly electrical conductivity (EC) measurements were obtained along with sample analyses. Data analysis performed in this study yielded a ratio between TDS and EC of 0.66, which was used to fill in some of the gaps where only EC measurements had been taken.

Flux, defined as total dissolved solids (or ion) in mg/l multiplied by the discharge in m^3, was calculated for each month at each station. The salt balance or change in storage (mass inflow – mass outflow) between stations was then obtained by subtracting the flux downstream from the flux upstream. The New Mexico portion of the Project had a negative (good) salt balance before 1963, but after 1980, a positive (bad) balance. The Texas portion of the Project had a positive balance before the mid 1970s. Since then it has leveled off and changed to a negative balance.

Autoregressive Integrated Moving Average (ARIMA) time series models, consisting of one non-seasonal autoregressive and one seasonal moving average parameter, adequately describe the salt balance behavior in most cases. However, the values of the parameters vary from ion to ion, station to station, and between the two time periods (1934-1963 and 1980-1994). Forecast values obtained from these models should be compared with actual data collected after 1994. An on-going consistent data collection program is needed, along with model maintenance.

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The compact disc containing this data is located in the Branson Library, New Mexico State University, Las Cruces, New Mexico

1.0 INTRODUCTION

1.1 Project Description

Thirty to forty percent of crops are produced from irrigated lands and we are currently losing irrigated land at the rate of about 22 million acres a year, while the world population continues to grow. Per-capita irrigated area peaked in 1978 and had fallen 5 percent by 1999. By 2020, per-capita irrigated area is projected to be 17-28 percent below the 1978 peak, according to Postel (1999). In addition, crop production is being significantly affected on much of the remaining land due to the build-up of salts in the soil. We are also experiencing reductions in crop yield due to salinity on over 25% of the 50 million acres of irrigated land in the western United States, with another 25% being threatened (Cuenca, 1989). Locally, the Rio Grande Project may be moving along a similar path. If indeed it really is threatened, we need to know while there is still time to do something about it.

The major purpose of this study was to determine the magnitude and distribution both temporally and spatially of salt within the Project, using historical data. In addition, Autoregressive Integrated Moving Average (ARIMA) time series models have been constructed representing salt balance (TDS and some major ions) conditions for the river reaches between stations for the period from 1934 to 1963. Models also have been constructed for the 15-year period from 1980 to 1994 for all stations. The changes in salt balance conditions between El Paso and Ft. Quitman were too complex to fit a model that passes all the diagnostic tests. However, the "best" fit model is discussed. The majority of the models appear to be adequate for forecasting purposes.

1.2 Rio Grande Project

1.2.1 Historical Background

The following statistics and quotes are from Weeden and Maddock (1999) unless otherwise attributed. Most of the statistics were taken from an earlier work (Hamilton and Maddock,1993). In 1907 Lee stated "The Rio Grande is essentially a storm-water stream, subject to great and sudden floods." as quoted in Weeden and Maddock (1999).   Between 1897 and 1905 the annual Rio Grande discharge at El Paso varied from a minimum of 50,768 acre-feet in 1902 to a maximum of 2,011,794 acre-feet in 1905. C.S. Slichter reported that the Rio Grande was dry for several months in 1904 at El Paso, Texas. To address fluctuations and depletions of the Rio Grande, the Elephant Butte Dam was available for storage starting in 1915, although construction was not completed until 1916 (Magallanez, 1998). Elephant Butte Reservoir can presently store approximately 2 million acre-feet of water (Magallanez, 1998).

Flows into Elephant Butte Reservoir still vary dramatically. The minimum inflow (114,100 acre-feet in 1951) was only 4% of the maximum inflow (2,831,000 acre-feet in 1941).   Weeden and Maddock (1999) report the average inflow into Elephant Butte Reservoir from 1915 to 1990 as 872,588 acre-feet with a standard deviation of 537,969 acre-feet. "This high standard deviation reflects the incredibly variable nature of annual precipitation events and runoff within the region" (quoted by Weeden and Maddock, 1999 from Hamilton and Maddock, 1993). Outflows from Elephant Butte reservoir reflect management of the water resource. The average release for the same time period was 723,147 acre-feet with a standard deviation of 265,537 acre-feet (Weeden and Maddock, 1999).

In 1938, the Caballo Dam was completed. Located approximately 25 miles south of Elephant Butte Dam, Caballo Reservoir can store 343,990 acre-feet of water (Magallanez, 1998). Caballo Reservoir operations control the Rio Grande flow into the Rincon and Mesilla Valleys downstream. However, flows released from Caballo Reservoir are dependent on releases from Elephant Butte Dam. Elephant Butte Dam includes a hydroelectric power plant; consequently water is released throughout the year. Winter releases from power generation are then stored in Caballo Reservoir for agricultural use during the irrigation season.

Between 1938 and 1989 the average release from Caballo Dam was 667,792 acre-feet (Weeden and Maddock, 1999). Wilson et al. (1981) report that 97% of Caballo Dam releases occur during the irrigation season between March and September. Outflow from the Mesilla Valley is represented by discharge of the Rio Grande past El Paso, Texas. The difference between the flow at Caballo Dam and El Paso is the total depletion occurring in that stretch of the Rio Grande.

The flow below Caballo Dam is the controlled release into the Rio Grande. However, the "flow of the Rio Grande at El Paso reflects a combination of reservoir releases, canal waste, water returned to the river from the drain system, discharge to the river from the ephemeral tributaries and sewage discharge from Las Cruces and Anthony" (Weeden and Maddock [1999] as cited from Maddock and Wright Water Engineers Inc, 1987). Rio Grande depletions between the Rio Grande below Caballo Dam and the Rio Grande at El Paso reflect the amount of water that was consumptively used by crops and natural vegetation, evaporated from surface waters, recharge to groundwater, minus tributary water and groundwater inflow. Consumptive use is calculated as outflow from Caballo Reservoir minus flows past El Paso.

1.2.2 Physical Description

The Rio Grande Project (RGP), providing irrigation water to the Rincon, Mesilla, and El Paso Valleys include the Rio Grande and a complex network of canals, laterals, and drains. Canals and laterals deliver water to agriculture, whereas drains collect and remove groundwater from agricultural areas (to remove salt and prevent water-logging) and return it for further use downstream. The system is gravity driven. Canals, most of which are unlined, are at higher elevations than the surrounding fields so that water flows under gravity to the fields. The drains are at lower elevations than the surrounding fields so that water that is not used by crops flows down gradient to the drains. Drain water represents the diverted water minus operational spills, consumptive use of water by crops and natural vegetation, minus evaporation from surface water in both the canals and drains, minus recharge to groundwater. In addition to the man-made features there are several major ephemeral streams within the RGP, including Percha Creek and Rincon Arroyo, which add significant flows to the Rio Grande after precipitation events.

The RGP extends along the Rio Grande from Caballo Dam to the El Paso-Hudspeth County line in Texas, a distance of 154 river miles (see Fig. 1). The project is separated into three divisions by natural barriers along the river channel. The upper division, known at the Rincon Valley, starts at Caballo Dam and extends downstream about 45 miles to Leasburg Dam. The next, the Mesilla Valley, starts at Leasburg Dam and extends 63 miles to American Dam just above El Paso. The lower division, known at the El Paso Valley, starts at American Dam and extends 46 miles on the United States side to the El Paso-Hudspeth County line. The total irrigated area in the Rio Grande Project is approximately 159, 650 acres, with 90,640 acres in the Elephant Butte Irrigation District (EBID) and 69,010 acres in the El Paso County Water Improvement District No. 1 (EPCWID).

Two small irrigation systems that pre-date the RGP are supplied from Caballo Dam. The Bonito Lateral diverts water directly from Caballo Dam, and the Percha Lateral diverts water from Percha Dam. The sum of the irrigated acreage of the two systems is small, and the water delivered to them is not counted as part of the release from Caballo. Although they create some problems with the salt balance, they are so small that their effect is negligible.

Water for the Rincon Valley portion of EBID is diverted at Percha Diversion Dam approximately two miles downstream from Caballo Dam. The Rincon Valley

Main Canal, which carries water for the irrigation of 16,260 acres in the Rincon Valley, has an initial capacity of 350 cubic feet per second.

The Leasburg Diversion Dam, located about 45 miles downstream from Caballo Dam, 15 miles northwest of Las Cruces, and 62 miles north of El Paso diverts water into the Leasburg Canal south of Selden Canyon, near Radium Springs. The canal, 13.7 miles long with an initial capacity of 625 cubic feet per second, irrigates 31,600 acres of the upper Mesilla Valley. The Mesilla Diversion Dam, approximately six miles south of Las Cruces and 40 miles north of El Paso, diverts water into the East Side and West Side Canals for the lower 53,650 acres of the Mesilla Valley irrigation system. The command area of the Mesilla Dam system includes 42,770 acres in EBID and 10,880 acres in EPCWID. The East Side Canal is 13.5 miles long and has an initial capacity of 300 cubic feet per second. The West Side Canal is 23.5 miles long and has an initial capacity of 650 cubic feet per second. Near its terminus, the West Side Canal system crosses under the Rio Grande in the Montoya Siphon.

To supply water to the El Paso Valley, water is diverted at the American Diversion Dam, on the Rio Grande 2 miles northwest of El Paso and immediately above the point where the river becomes the international boundary line. This diversion is operated by the American Section of the International Boundary and Water Commission (IBWC) to regulate delivery of water to Mexico in accordance with treaty provisions. The American Canal carries water 2.1 miles from the dam to the head of Franklin Canal. The initial capacity of the American Canal is 1,200 cubic feet per second. The Franklin Canal, which conveys water to El Paso Valley, is 28.4 miles long, has an initial capacity of 325 cubic feet per second, and serves 17,000 acres in the upper portion of the El Paso Valley.

The Riverside Diversion Dam, the southernmost project diversion point, is on the Rio Grande 15 miles southeast of El Paso, and diverts water into the Riverside Canal. This canal is 17.2 miles long, has an initial capacity of 900 cubic feet per second, serves 39,000 acres in the lower portion of the El Paso Valley, and carries any available surplus through to the Hudspeth District. The Tornillo Canal, a continuation of Riverside Canal, is 12 miles long and has an initial capacity of 325 cubic feet per second. The Riverside Diversion has not been used extensively since storm flows in the 1980s damaged the structure.

Hudspeth County Conservation and Reclamation District (HCCRD) provides irrigation water to 18,000 acres in Hudspeth County, Texas. HCCRD is not a part of the RGP, but it does store and divert storm waters, drain flows, and canal tail water from EPCWID.

1.3 Objectives

The objectives of this research are:

1. To compile available monthly flow and water quality data (major ions) from river stations within the Rio Grande Project for as long a period of data coverage as possible;

2. To develop coefficients for relating total dissolved solids (TDS) to EC_{25} (electrical conductivity at 25°C), and for estimating TDS when only EC_{25} is measured;
3. To develop ratios of each major ion to TDS for each month of the year and each station, so that concentrations of each major ion can be estimated from a measurement of TDS;
4. To examine the monthly and cumulative salt balance (mass inflow of salt minus mass outflow of salt) and balances of individual major ions for each of the three valleys in the RGP for as long a period of data coverage as possible;
5. To develop autoregressive integrated moving average (ARIMA) time series models of salt balance for each river reach between stations, to allow forecasting for operations management.

1.4 Scope and Limitations

The work presented here is based on existing historical flow and water quality data. No new measurements were taken for this work, because the objective was to develop as long a time series as possible using the historical data. The focus in water quality was on major ions (calcium, magnesium, sodium, sulfate, carbonate/bicarbonate, and chloride), although where data were readily available, boron and nitrate were presented for information purposes but not discussed.

The salt balance presented in this study is a gross simplification of a highly complex hydrologic and geohydrologic system. Each of the valleys is treated as a black box, with one source and one outlet. In reality, there are precipitation and dissolution processes occurring, tributary salt and water flows from local groundwater systems, imported water pumped in from hydrologically isolated aquifers for municipal use, addition of mineral fertilizers, and other factors that this simple approach ignores. However, on a long-term basis, the salt balance is a useful indicator of the health of the hydrologic unit of a valley in terms of salt accumulation.

The estimates of TDS based on EC_{25} and the estimates of each major ion concentration based on monthly ratios for each month and each station are by no means a substitute for chemical analyses to determine these parameters. Changing water use and changes in aquifer sources may cause the relationships presented here to change with time. The immediate purpose of these relationships is to allow estimation of missing data to produce continuous, consistent water quality time series. The relationships derived can be used for future monitoring efforts, but regular checks are needed to ensure that the relationship between EC_{25} and TDS, and the monthly ion ratios for each site, are not changing significantly.

Where multiple conflicting data from different sources were available for a given month, the data point that was most consistent with the data immediately before and after the point in question was chosen. Several gaps (TDS or individual ions) occurred in the available data. For short gaps, four months or less, missing data were estimated as described in the methodology section. Where larger gaps occurred, no attempt was made to estimate the missing data. Estimated data are annotated in the appendices.

2.0 LITERATURE REVIEW

2.1 Wilcox

From 1934 through 1963, L. V. Wilcox of the U.S.D.A. Salinity Laboratory in Riverside, California was posted in the RGP area to systematically collect salinity data within the Project area. He worked primarily with U.S. Bureau of Reclamation personnel who were managing the project at that time. Bureau personnel responsible for gate settings and flow measurement were given a gallon jug and instructed to collect a sample of a standard volume each day and pour it into the jug. At the end of the month, Wilcox collected all of the jugs and took them to a central laboratory in El Paso where they were analyzed for EC_{25}, TDS by filtration and residue on evaporation, and major ions by standard methods. The reported data (Wilcox, 1968) were therefore a time-weighted monthly average rather than a flow-weighted monthly average. While a flow-weighted average would be preferable for determining the salt inflow, outflow, and balance, the errors introduced by the time-weighted average should be fairly small and unbiased.

2.2 Hernandez

In 1975, J.W. Hernandez, of the College of Engineering at New Mexico State University at Las Cruces, New Mexico performed a study of the water quality in the Rio Grande Project. This work (Hernandez, 1976) included compiling historical water quality data and providing a one-year record of water quality for the major drains, canals, effluent discharges, and the Rio Grande.   Water samples were taken in March, June, September, late October, and late December of 1975, at 45 stations extending from San Marcial to the heading of the Riverside Canal. The sample timing was intended to be representative of the varying seasonal conditions that are characteristic of the annual irrigation cycle.

Some of the pertinent findings of the study are as follows: 1) TDS and corresponding concentrations of both anions and cations increased in the downstream direction, 2) there was a distinct seasonal variation in TDS in the river and canal samples, 3) a general but inconsistent relationship existing between the ions and TDS, 4) the range of seasonal variations in water quality increased in the downstream direction, and 5) water quality decreased with low flows and increased during periods of water release and storm discharge. One recommendation made by Hernandez was that an analysis be performed to determine the ratio of TDS to electrical conductivity for the various stations as a check on future quality.

2.3 Miyamoto

The study by Miyamoto et al. (1995), conducted for the years 1969-1989, focused on flow and water quality in the Rio Grande from El Paso to the Gulf of Mexico and was based on data obtained from the International Water and Boundary Commission. Some of the significant findings include the following: 1) salt is the major constraint for full utilization of the Rio Grande, 2) salinity steadily increased at significant rates (15 mg/L per year at Amistad Dam), and had not reached a steady state 3) salinity is flow dependent at El Paso and Ft. Quitman, 4) salinity of the Rio

Grande main flow reaching El Paso averaged 1,000 mg/l, and increased by a factor of 3.0 at Ft. Quitman, 5) salinity decreases during the irrigation season (March 15 to September 15) and increases during the off-season, and 6) salts have been accumulating in the lands along the Rio Grande and are expected to continue to do so.

3.0 METHODOLOGY

3.1 Collection, Compilation, and Reconciliation of Data

Data used in this study were taken from reports compiled by Wilcox (1968), Hernandez (1976), and directly from the U.S. Geological Survey for river gaging stations at San Marcial, New Mexico, located just above Elephant Butte Reservoir, below Elephant Butte Dam, below Caballo Dam, above Leasburg Dam, the Courchesne Bridge at El Paso, Texas and Ft. Quitman, Texas. Flow measurements and water samples have been taken at these various gaging stations by the USGS, the U.S. Bureau of Reclamation, and the International Boundary and Water Commission monthly from 1934 to 1963. From 1963 to the present, flow measurements were taken monthly, with limited water quality data collected between 1963 and 1980. El Paso and Ft. Quitman were the exceptions, with El Paso data being complete from January 1934 through September 1994 and Ft. Quitman data from January 1934 through March 1988. From 1980 through 1994 water quality data in terms of TDS, with some gaps, were obtained. After 1994, the water quality data are significantly incomplete. Because the data are not continuous after 1963, the 30-year period from 1934 to 1963 served as a means of estimating missing data.

The data compiled and published by Wilcox (1968) and Hernandez (1976) were compared with original data now available from the USGS and USBR. When differences were found, comparisons were made with adjacent points and the corresponding months of other years to determine which values were most likely correct. In the few cases that remained questionable, the USGS data were used, except for the carbonate/bicarbonate ion data at El Paso. The data published by the USGS for this ion differed consistently by a factor of 2 from Wilcox and Hernandez. This reflects the valence difference between carbonate and bicarbonate as recorded by the participating agencies analyzing the samples. Adjustments were made to obtain consistent data.

Where there were multiple TDS data points for the same month, a time-weighted average was calculated and used for that month. In cases of the occasional missing data point or a short series of missing points, straight-line interpolation was used to complete the series.

3.2 Characteristics of Salinity in the Rio Grande Project

3.2.1 Ratio of TDS to EC_{25}

During the years from 1934 to 1963, electrical conductivity (mS/cm at 25°C) measurements were taken concurrently with chemical analyses for each month at each of the river gaging stations and the major drains. This study used the published Wilcox (1968) data for both the river stations and the drains. These total approximately 3,800 monthly data points over the thirty-year span. After discarding the outliers with values exceeding 1.0, statistical analyses were performed as a means of evaluating the results.

There were some instances in the data where only EC_{25} measurements were recorded. In these cases, the TDS to EC_{25} ratio determined in this study was used to estimate values for TDS. The TDS values calculated using this method are annotated in the spreadsheets on the compact disc.

3.2.2 Individual Ions as a Percentage of TDS

Ratios of the major ions to TDS were calculated for all stations for each month, using the data sets that were complete (1934-1963). These ratios were then used to compute missing data points for the years after 1980. The individual ion values calculated by this method are annotated.

To estimate the accuracy of this method, the individual ion values from the *computed* ratios were compared with the *actual* individual ion values for El Paso at Courchesne Bridge. These data were used because the El Paso record is nearly complete for the years from 1934-1994. The computed monthly ratios for each of the major ions for El Paso are shown in Table 1. There is overlap of the 95% confidence intervals between the actual and computed ion values for all 12 months of the year and all the major ions (except for HCO_3 in June and July). Statistical analysis indicates that this method should generate ion values for the other stations that are reliable at the 95 percent confidence level. A summary of the results of this comparison using computed monthly ratios is presented as Appendix A.

Table 1. Computed average monthly ion/TDS ratios at Courchesne Bridge

Month/Ion	Calcium	Magnesium	Sodium	Carbonate	Sulfate	Chloride
Jan	0.0826	0.0201	0.2239	0.0958	0.3174	0.2052
Feb	0.0841	0.0201	0.2183	0.0964	0.3226	0.1966
Mar	0.1132	0.0246	0.1936	0.1270	0.3434	0.1754
Apr	0.1152	0.0253	0.1872	0.1293	0.3462	0.1611
May	0.1091	0.0248	0.1839	0.1244	0.3376	0.1568
Jun	0.1125	0.0243	0.1754	0.1326	0.3312	0.1463
Jul	0.1115	0.0245	0.1749	0.1360	0.3264	0.1446
Aug	0.1121	0.0239	0.1717	0.1368	0.3196	0.1440
Sep	0.1081	0.0234	0.1816	0.1258	0.3228	0.1579
Oct	0.0887	0.0210	0.2096	0.1020	0.3198	0.1907
Nov	0.0869	0.0205	0.2163	0.1006	0.3184	0.1970
Dec	0.0870	0.0205	0.2144	0.1014	0.3138	0.1960

3.3 Salt and Ion Balances in the Rio Grande Project

Wilcox (1968) stated that Scofield originated and defined the term “salt balance” in the statement: “If the mass of the salt input exceeds the mass of the salt output, the salt balance is regarded as adverse, because the trend is in the direction of accumulation of salt in the area, and such a trend is manifestly undesirable.” In other words, if the salt balance is positive from gaging station to gaging station, then there is an apparent accumulation of salt within the reach in question. Because there are limits on how much salt plants can tolerate and remain productive, it becomes important to not exceed these limits in the long term. If the salt balance is negative, then salt is not accumulating within the study area soils, but is being transported downstream, which is important to downstream water users.

Flux, defined as total dissolved solids (or ion) in mg/l multiplied by the flow in m^3 (resulting in units of grams, and generally expressed in metric tons) was calculated for each month at each gaging station. The salt balance or change in storage (salt mass inflow - salt mass outflow) between stations (from San Marcial to Elephant Butte, from Elephant Butte to Caballo, from Caballo to Leasburg, from Leasburg to El Paso, from El Paso to Ft. Quitman, and from Elephant Butte to El Paso) was then obtained by subtracting the flux downstream from the flux upstream.

3.4 ARIMA Modeling

In general, the two primary goals of conducting a time series analysis are: (a) characterizing the nature of the phenomenon represented by the sequence of observations, and (b) forecasting or predicting future values of the time series variable. The focus of this study is on the forecasting capabilities of the models.

Hydrologic processes usually exhibit time dependence, known as autocorrelation, between a given observation at some time *t* denoted by z_t and some previous observation(s), z_{t-1}, z_{t-2}, etc., and with those occurring at the same time during the previous season(s), denoted by z_{t-s}. In the RGP, salt balance for both TDS and the major ions for each river reach between stations can be modeled with multiplicative autoregressive integrated moving average time series models, developed by Box and Jenkins (1976), denoted as ARIMA $(p,d,q) \times (P,D,Q)_s$, where

p = order of the non-seasonal autoregressive process,
d = number of consecutive differencing,
q = order of the non-seasonal moving average process,
P = order of the seasonal autoregressive process,
D = number of seasonal differencing,
Q = order of the seasonal moving average process, and
s = the span of the seasonality.

The ARIMA methodology has gained enormous popularity in many areas, and research practice confirms its power and flexibility (Vandaele, 1983), especially when patterns of the data were unclear and individual observations involved considerable error. In this study their application to seasonal data is particularly important.

The Box-Jenkins approach consists of extracting the predictable movements from the observed data. It primarily makes use of three linear filters known as: the autoregressive, the integration, and the moving average filter. The objective in applying these filters is to end up with a white noise process, which is unpredictable. Once this is done successfully, we have a model that has properties similar to the process itself. This model can then provide a basis for accurate and reliable forecasts.

The time series analyses and modeling for this study were done using the computer program *Statistica* for Windows, by StatSoft, Inc.(1999), 2300 East 14th Street, Tulsa, OK 74104.

4.0 RESULTS AND DISCUSSION

4.1 Collection, Compilation, and Reconciliation of Data

It should be recognized that the data used in this study have some inherent inaccuracies due to differences in data collection procedures and methods used in chemical analyses performed over a relatively long period of time by different entities. The time gap (1963-1980) in the water quality data presents the unfortunate requirement of starting at time zero in terms of establishing salt and ion balance trends and forecasting the future. However, it may be of some value to examine the relationships during each of the two time periods.

The data were first transferred directly from the available hard-copy records from Wilcox, Hernandez, and the USGS to Microsoft excel spreadsheets. As a means of checking for discrepancies, the individual ion concentrations were summed with the total calculated as a percentage of TDS. When this total exceeded 100%, the data for each individual ion were checked against the hard copies from all sources. In most cases, the errors were relatively easy to detect and correct using the procedures discussed previously in the methodology section. However, in those remaining cases where it was not possible to determine the correct numbers with an acceptable degree of certainty, the numbers were left as they were found, with the USGS data (when available) being the final choice. When there were no USGS data available, the Wilcox data were used. It should be noted that all of the reconciliation done in this study was based on the judgment of this author. Therefore, the reader may wish to review the original hard-copy records and compare them with the electronic versions of the original data and the corrected data, both of which are available on a CD-ROM at the NMSU Branson Library.

4.2 Characteristics of Salinity in the Rio Grande Project

4.2.1 Ratio of TDS to EC_{25}

During the 30 years between 1934 and 1963 monthly electrical conductivity (EC) measurements were obtained along with sample analyses. Data analysis performed in this study yielded a ratio between TDS and EC of 0.66, which was used to fill in some of the gaps where only EC measurements had been taken. The results of the statistical analysis for determining this ratio are summarized in Table 2. This ratio applies to all stations.

Table 2. Statistical analysis summary of the ratio of TDS to EC_{25}.

Number of Points	TDS/EC Ratio	Standard Deviation	95% C.I.		99% C.I.	
			Lower	Upper	Lower	Upper
3573	0.6581	0.0332	0.6570	0.6592	0.6567	0.6595

I am 99% confident that the mean of the ratio of total dissolved solids (mg/l) to electrical conductivity (microsiemens/cm at 25° Celsius) in the Rio Grande Project is between 0.657 and 0.660. I rounded to two significant figures and used 0.66. This level of precision is warranted considering the errors inherent in taking samples and measurements and performing chemical analyses. By way of comparison, Miyamoto et al. (1995) found the same ratio in the Rio Grande for the reach from Ft. Quitman to Brownsville for the years from 1969 to 1989. However, the ratio for El Paso was found to be 0.69 in the study by Miyamoto, as opposed to 0.66 in this study. It is unclear why there would be a difference because the data used in obtaining this ratio in this study would have also been available to Miyamoto. The 0.66 obtained in this study was also compared with the 1934-1963 data for El Paso at Courchesne Bridge with the result that there was no change in the ratio.

4.2.2 Individual Ions as a Percentage of TDS

Ratios of the major ions to TDS were calculated for all stations for each month. However, at the outset of this study, ratios were calculated without due consideration of any seasonal variation that might be present. A simple average using the Wilcox data (1934-1963) was obtained for each ion at each gaging station. When the computed data were compared with the actual data at Courchesne Bridge it was determined that the variation from month to month might be significant enough to warrant further examination. Figure 2 graphically illustrates the seasonal variation of the ion to TDS ratio in the Rio Grande at Courchesne Bridge.

As the graph illustrates, the variations in the ratios for sodium and chloride, and calcium and carbonate have very definite seasonal patterns that follow the irrigation year that generally runs from March through September. Ratios of sodium and chloride ion to TDS both decrease through the height of the irrigation season while at the same time calcium and carbonate ratios increase in a mirroring pattern. The ion to TDS ratios in the Rio Grande below Elephant Butte Dam are relatively constant through the year as shown in Figure 3, indicating that return flows are responsible for the monthly changes in ion ratios that occur at Courchesne Bridge.

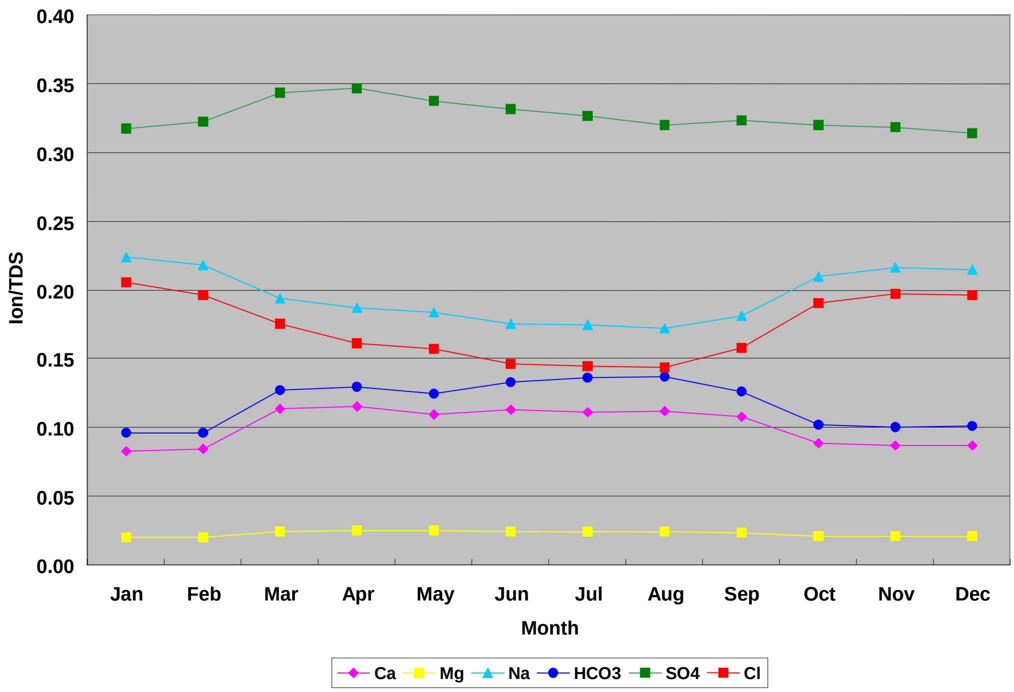


Figure 2. Seasonal variation of ion to TDS ratios (average, n =30) in the Rio Grande at Courchesne Bridge.

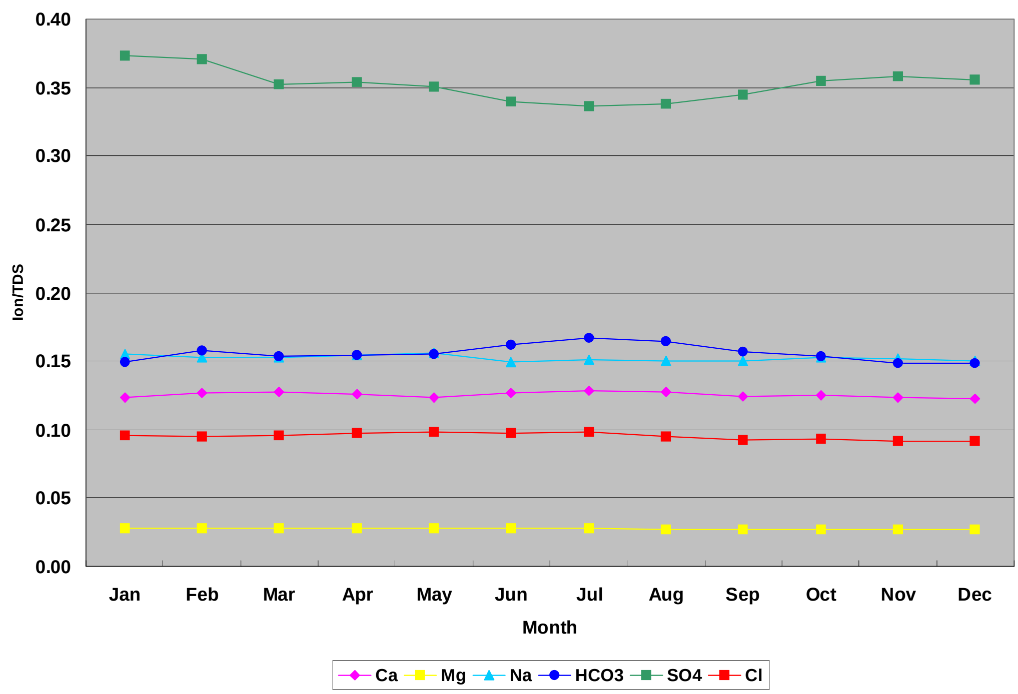


Figure 3. Seasonal variation of ion to TDS ratios (average, n = 30) in the Rio Grande below Elephant Butte Dam.

In addition to seasonal variations, the two graphs taken together illustrate the fact that there are definite and significant changes in the ratios as we move downstream in the RGP. The same observation was made by Hernandez (1976). This underlines the importance of using ratios that are site-specific for each station. This is graphically illustrated in Figure 4. The values for each station are the annual averages.

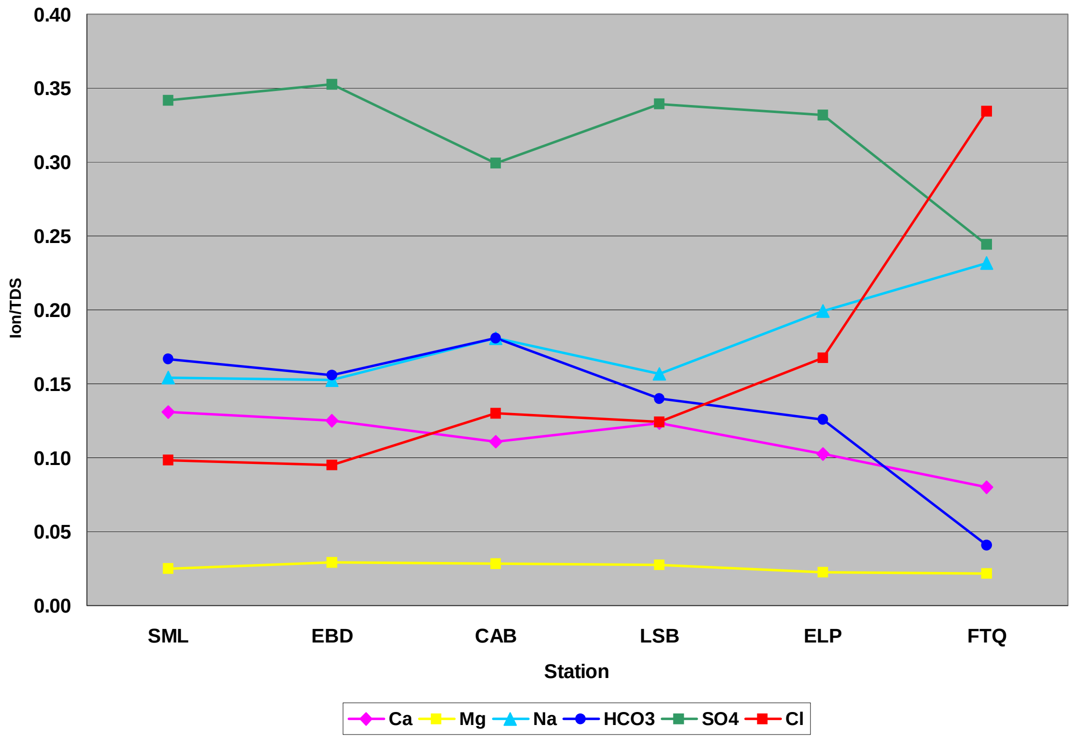


Figure 4. Annual average ion to TDS ratios in the Rio Grande Project (1934-1963).

The average monthly ratios for all the stations used in this study are shown below in Tables 3-8, and graphically in Appendix B for visual comparison.

Table 3. Ion/TDS ratios at San Marcial, just above Elephant Butte Reservoir.

Month/Ion	Ca	Mg	Na	HCO_3	SO_4	Cl
Jan	0.1324	0.0252	0.1546	0.1812	0.3107	0.1129
Feb	0.1317	0.0250	0.1557	0.1804	0.3210	0.1066
Mar	0.1299	0.0260	0.1573	0.1774	0.3257	0.1019
Apr	0.1310	0.0259	0.1546	0.1829	0.3157	0.1045
May	0.1354	0.0250	0.1430	0.1957	0.2869	0.0961
Jun	0.1311	0.0255	0.1502	0.1828	0.3117	0.0994
Jul	0.1321	0.0255	0.1543	0.1807	0.3204	0.1048
Aug	0.1329	0.0251	0.1475	0.1187	0.4242	0.0780
Sep	0.1285	0.0250	0.1567	0.1287	0.4225	0.0815
Oct	0.1279	0.0263	0.1747	0.1489	0.4105	0.0993
Nov	0.1332	0.0254	0.1566	0.1807	0.3297	0.1037
Dec	0.1383	0.0261	0.1489	0.1866	0.3167	0.1035

Table 4. Ion/TDS ratios at Elephant Butte Dam

Month/Ion	Ca	Mg	Na	HCO_3	SO_4	Cl
Jan	0.1233	0.0276	0.1550	0.1489	0.3730	0.0958
Feb	0.1263	0.0277	0.1527	0.1579	0.3709	0.0944
Mar	0.1273	0.0276	0.1525	0.1534	0.3525	0.0958
Apr	0.1255	0.0277	0.1540	0.1541	0.3535	0.0969
May	0.1236	0.0278	0.1558	0.1552	0.3506	0.0981
Jun	0.1266	0.0281	0.1496	0.1620	0.3396	0.0974
Jul	0.1285	0.0277	0.1509	0.1669	0.3365	0.0981
Aug	0.1272	0.0270	0.1502	0.1640	0.3382	0.0951
Sep	0.1242	0.0270	0.1503	0.1572	0.3448	0.0926
Oct	0.1247	0.0271	0.1527	0.1531	0.3544	0.0932
Nov	0.1233	0.0266	0.1516	0.1487	0.3583	0.0916
Dec	0.1226	0.0269	0.1502	0.1484	0.3558	0.0917

Table 5. Ion/TDS ratios in the Rio Grande below Caballo Dam

Month/Ion	Ca	Mg	Na	HCO_3	SO_4	Cl
Jan	0.0859	0.0306	0.2228	0.2154	0.2528	0.1501
Feb	0.0909	0.0301	0.2109	0.2027	0.2663	0.1444
Mar	0.1264	0.0269	0.1580	0.1539	0.3210	0.1333
Apr	0.1269	0.0273	0.1534	0.1579	0.3362	0.1139
May	0.1238	0.0277	0.1563	0.1587	0.3330	0.1132
Jun	0.1248	0.0275	0.1548	0.1620	0.3320	0.1108
Jul	0.1244	0.0276	0.1560	0.1666	0.3284	0.1100
Aug	0.1279	0.0270	0.1533	0.1715	0.3144	0.1122
Sep	0.1264	0.0271	0.1579	0.1695	0.3165	0.1195
Oct	0.0922	0.0287	0.2100	0.1925	0.2714	0.1497
Nov	0.0904	0.0295	0.2177	0.2060	0.2598	0.1533
Dec	0.0902	0.0302	0.2180	0.2138	0.2539	0.1503

Table 6. Ion/TDS ratios in the Rio Grande above Leasburg Dam

Month/Ion	Ca	Mg	Na	HCO_3	SO_4	Cl
Jan	0.1216	0.0254	0.1596	0.1156	0.3551	0.1424
Feb	0.1232	0.0265	0.1586	0.1313	0.3554	0.1287
Mar	0.1283	0.0257	0.1537	0.1504	0.3234	0.1221
Apr	0.1273	0.0263	0.1548	0.1424	0.3278	0.1154
May	0.1239	0.0262	0.1573	0.1449	0.3331	0.1157
Jun	0.1239	0.0268	0.1564	0.1402	0.3379	0.1182
Jul	0.1282	0.0269	0.1542	0.1591	0.3334	0.1131
Aug	0.1297	0.0258	0.1521	0.1554	0.3220	0.1137
Sep	0.1260	0.0272	0.1550	0.1493	0.3230	0.1233
Oct	0.1220	0.0254	0.1599	0.1258	0.3440	0.1356
Nov	0.1231	0.0253	0.1614	0.1212	0.3473	0.1409
Dec	0.1256	0.0253	0.1579	0.1251	0.3501	0.1394

Table 7. Ion/TDS ratios in the Rio Grande at Courchesne Bridge

Month/Ion	Ca	Mg	Na	HCO_3	SO_4	Cl
Jan	0.0826	0.0201	0.2239	0.0958	0.3174	0.2052
Feb	0.0841	0.0201	0.2183	0.0964	0.3226	0.1966
Mar	0.1132	0.0246	0.1936	0.1270	0.3434	0.1754
Apr	0.1152	0.0253	0.1872	0.1293	0.3462	0.1611
May	0.1091	0.0248	0.1839	0.1244	0.3376	0.1568
Jun	0.1125	0.0243	0.1754	0.1326	0.3312	0.1463
Jul	0.1115	0.0245	0.1749	0.1360	0.3264	0.1446
Aug	0.1121	0.0239	0.1717	0.1368	0.3196	0.1440
Sep	0.1081	0.0234	0.1816	0.1258	0.3228	0.1579
Oct	0.0887	0.0210	0.2096	0.1020	0.3198	0.1907
Nov	0.0869	0.0205	0.2163	0.1006	0.3184	0.1970
Dec	0.0870	0.0205	0.2144	0.1014	0.3138	0.1960

Table 8. Ion/TDS ratios in the Rio Grande at Ft. Quitman

Month/Ion	Ca	Mg	Na	HCO_3	SO_4	Cl
Jan	0.0818	0.0220	0.2282	0.0422	0.2420	0.3320
Feb	0.0804	0.0223	0.2308	0.0362	0.2380	0.3419
Mar	0.0775	0.0228	0.2316	0.0313	0.2305	0.3524
Apr	0.0840	0.0224	0.2271	0.0502	0.2402	0.3492
May	0.0964	0.0230	0.2261	0.0718	0.2494	0.3508
Jun	0.0925	0.0217	0.2138	0.0661	0.2450	0.3432
Jul	0.0972	0.0216	0.2106	0.0915	0.2421	0.3335
Aug	0.0936	0.0212	0.2157	0.0987	0.2343	0.3269
Sep	0.0885	0.0226	0.2209	0.0831	0.2419	0.3332
Oct	0.0880	0.0214	0.2244	0.0675	0.2483	0.3237
Nov	0.0850	0.0214	0.2259	0.0560	0.2406	0.3224
Dec	0.0835	0.0214	0.2267	0.0486	0.2461	0.3235

4.3 Salt and Ion Balances in the Rio Grande Project

4.3.1 General

The changes in the salt balance from station to station for both time periods are shown graphically in Figures 5-10. The time gap (from 1964–1980) in the data collected required that the salt balance computations start at zero again in 1979-1980 for all stations except El Paso and Ft. Quitman.

4.3.2 San Marcial to Elephant Butte Dam

The TDS salt balance from San Marcial to Elephant Butte exhibits an erratic behavior and is somewhat inconsistent, not only with the downstream river reaches but along its own time-line, as can be seen in Figure 5. However, the individual ion balances seem to generally support the changes in the TDS balance. One interesting observation is that the salt balances are generally trending to the positive during periods of higher flows and trending to the negative during periods of lower flows. This is counter-intuitive and so would invite further investigation. A positive balance would indicate accumulation of salt in Elephant Butte Reservoir, but the long-term TDS in the reservoir has not changed, and no significant evidence of precipitation of salt minerals in or around the reservoir has been documented. Groundwater outflows could explain some of the discrepancy, but it is unlikely that long-term seepage from the reservoir could be of a large enough magnitude to explain the strongly positive balance. We offer no explanation for this counter-intuitive behavior, though it certainly bears further investigation. It is also interesting to note that the sulfate ion balance closely follows the pattern displayed by the TDS salt balance in the earlier time period (1934-1963).

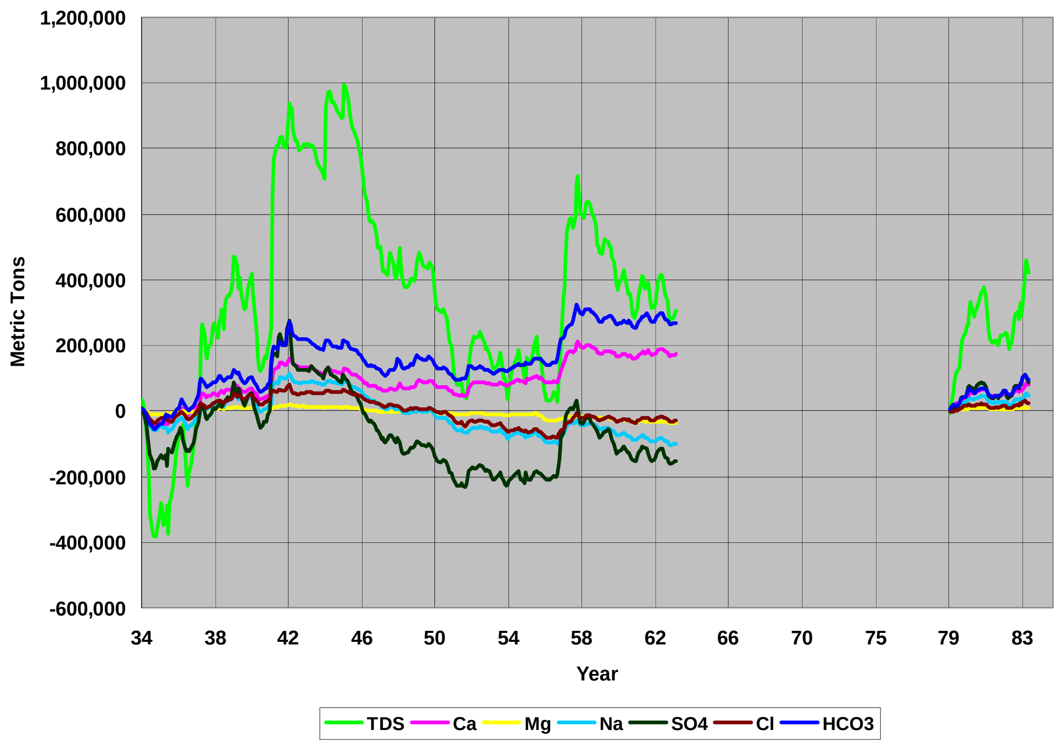


Figure 5. San Marcial-Elephant Butte salt balance

4.3.3 Elephant Butte Dam to Caballo Dam

With the exception of the sulfate ion balance, the patterns for both time spans from Elephant Butte to Caballo are very similar and are generally trending to a negative balance over time as illustrated in Figure 6. This negative balance is probably due to tributary flows into Caballo Reservoir from storm runoff. These storm flows would bring salt into the reservoir that did not come out of Elephant Butte Reservoir, thereby creating a negative balance. One notable exception occurred during the early to mid 1950s when there were essentially no significant changes in the TDS balance. This coincides with the drought that occurred at that time, and because the flow in the Rio Grande was relatively very low, Caballo Reservoir was essentially a flow-through system.

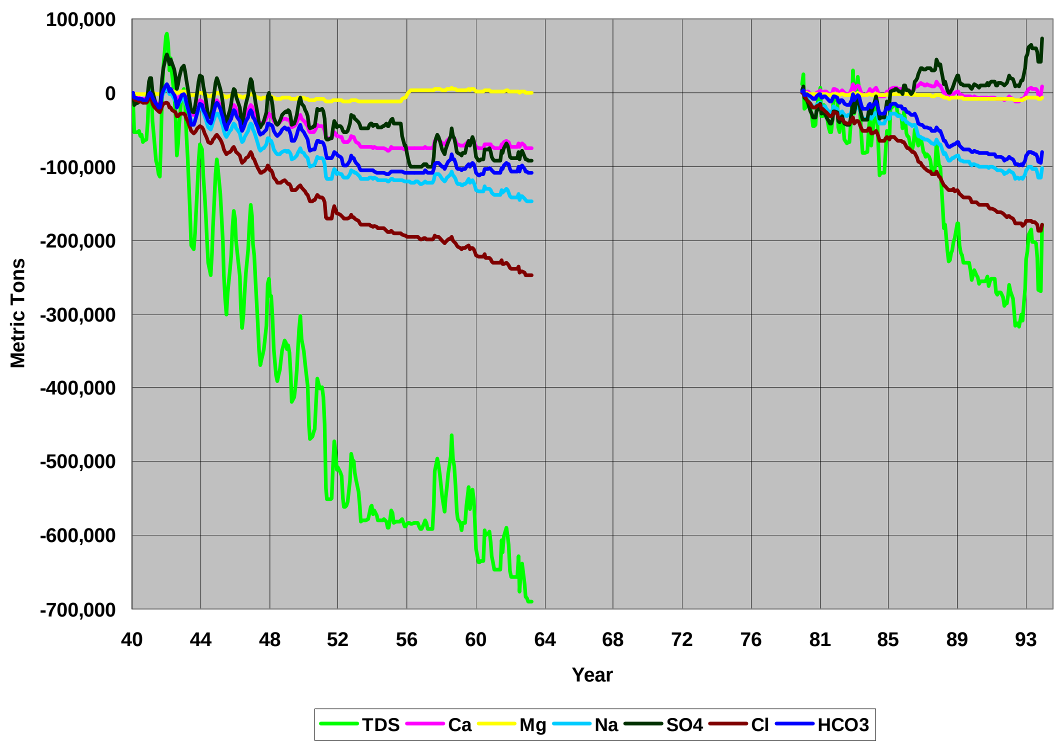


Figure 6. Elephant Butte-Caballo salt balance

4.3.4 Caballo Dam to Leasburg Dam

Part of the release from Caballo Dam is diverted two miles downstream at the Percha Diversion Dam into the Rincon Valley Main Canal, which then supplies irrigation water to the 16,260 acres in the Rincon Valley. With the exception of carbonate/bicarbonate, the salt balances follow a similar pattern, that is, a negative trend for both time periods (see Figure 7). This means that generally the salts are being flushed out of the valley soils and back into the river downstream. However, the carbonate/bicarbonate balance is slightly positive, indicating that they are precipitating out to some extent in the local soils.

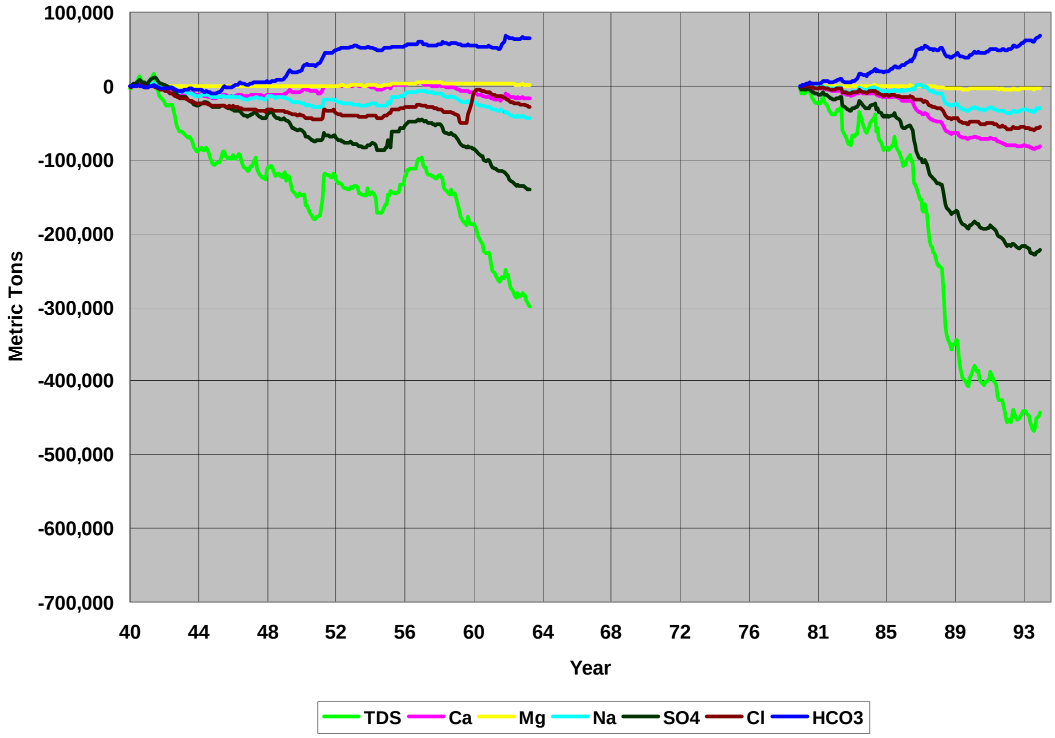


Figure 7. Caballo-Leasburg salt balance

4.3.5 Leasburg to Rio Grande at Courchesne Bridge

In the Mesilla Valley there were significant salt balance changes beginning with a severe drought of the 1950s. At this time local farmers began drilling wells and by 1955, 1,682 were in production, according to King, et al. (1971) quoting Spiegel. The lack of surface water coupled with pumping of groundwater produce a drop in groundwater levels that reduced or even eliminated flows from the drains. The TDS salt balance went from negative to positive in a relatively short period of time and in a drastic way, with an average net change of approximately 100,000 metric tons a year, as shown in Figure 8. These salts consist mostly of calcium, sulfate, and carbonate/bicarbonate. The trend since 1980 is essentially the same, possibly as a result of continued reliance on groundwater for irrigation and municipal supply.

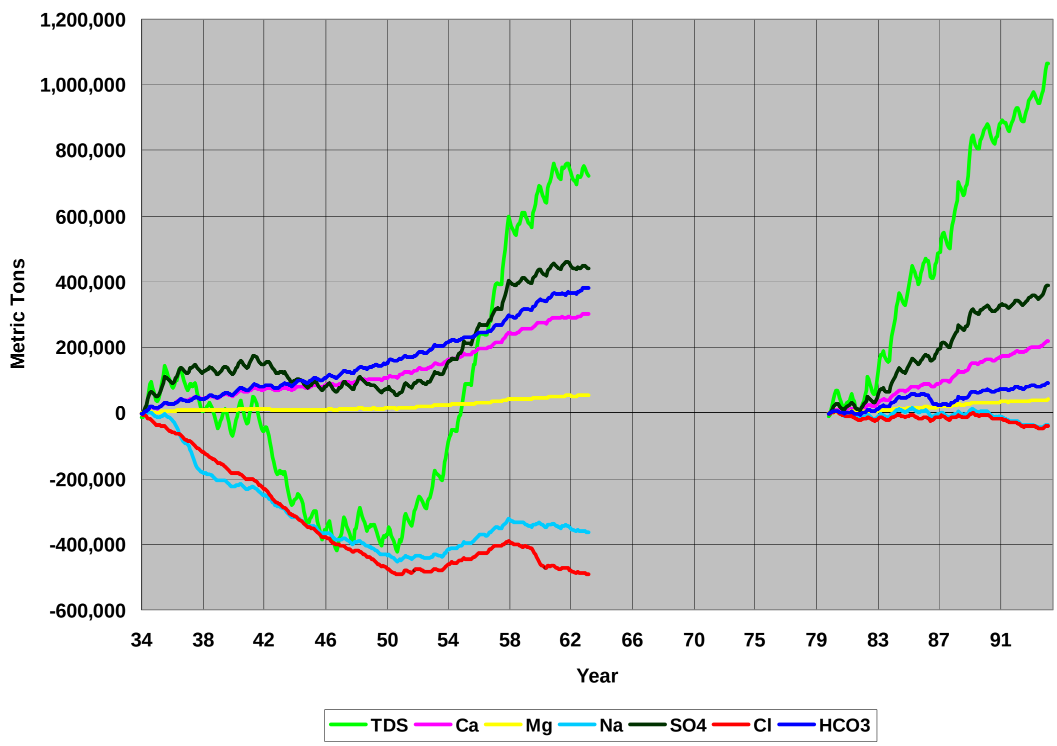


Figure 8. Leasburg-El Paso salt balance

4.3.6 Elephant Butte to Courchesne Bridge

The salt balance between New Mexico (plus the 10,880 acres of water-righted Texas land in the Mesilla Valley) and Texas is presented in Figure 9. The drought of the 1950s is once again very prominently reflected by the change in the TDS salt balance from negative trend to positive. However, most significant is that the TDS balance in now trending to the positive, meaning that salts are building up in the in the soils and groundwater of EBID.

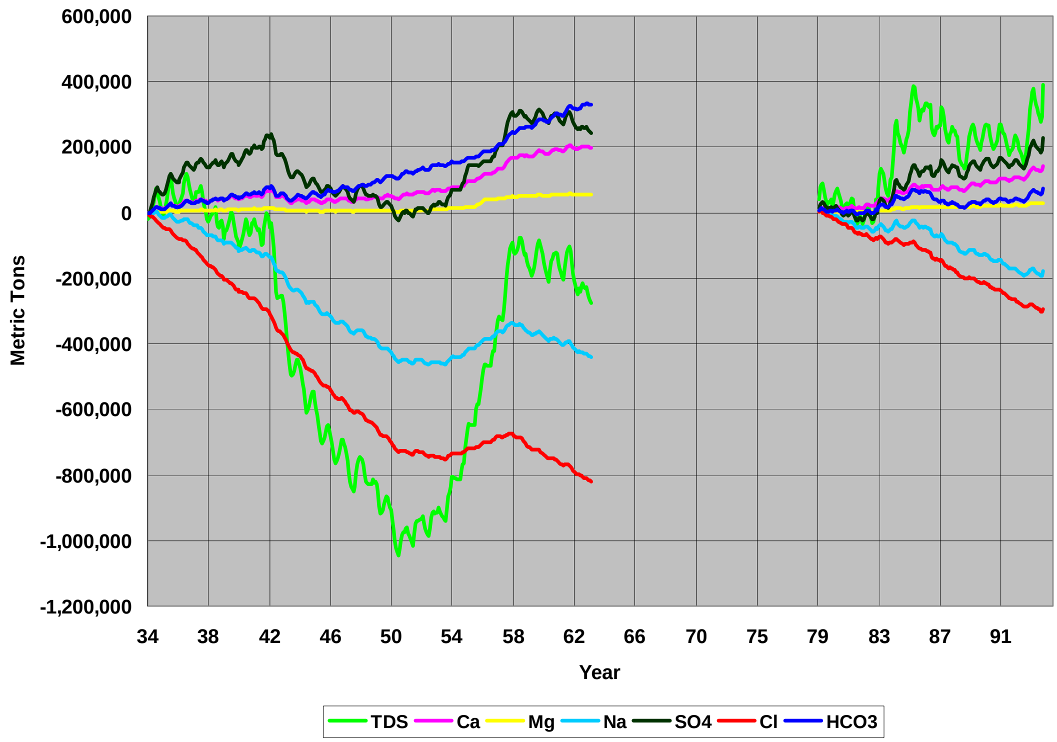


Figure 9. Elephant Butte-El Paso salt balance

The individual ion balances follow the same general trends for both time periods, with sodium and chloride exhibiting a negative balance while sulfate, calcium and carbonate are trending toward the positive.

4.3.7 Courchesne Bridge to Fort Quitman

The salt balances from Courchesne Bridge at El Paso to Ft. Quitman are shown in Figure 10. For over 50 years, from 1934 to about 1986, the salt balances for

TDS, sulfate, carbonate, and calcium were increasing at a relatively uniform rate, with sodium only slightly so.   TDS was steadily building up in the project soils. Chloride is a notable exception, and was being sent downstream. Then in the summer of 1986, there was a sudden change, with TDS reversing its trend from positive to negative.

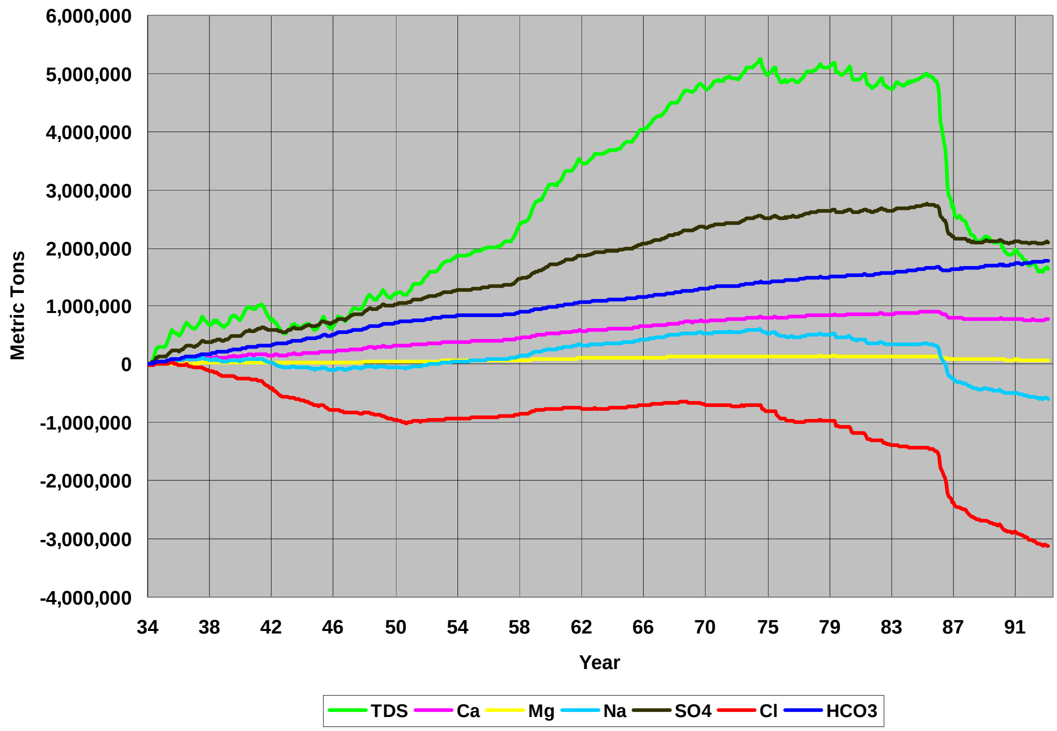


Figure 10. El Paso-Ft. Quitman salt balance

This corresponds to the high flows associated with the spill from Elephant Butte Dam that occurred in 1986. Miyamoto et al. (1995) discussed extensively the effect of this large outflow of salt on the downstream reach of the Rio Grande. The sulfate, sodium, and chloride ions were the major constituents. As interesting is the fact that the calcium and carbonate/bicarbonate ions were not significantly affected, and as always magnesium seems to be unaffected by anything. These large flows of fresh water essentially flushed out an amount of salt equivalent to the previous 30-year salt accumulation in the El Paso Valley.

4.4 ARIMA Modeling

4.4.1 Representative Model

Salt balance for TDS and the major ions, flow, and TDS (mg/l) were modeled using the Box-Jenkins methodology. The model that was found to be predominant has a non-seasonal autoregressive parameter at lag 1, a seasonal moving average parameter at lag 12, with both seasonal (order 12) and non-seasonal differences. Technically, the model is of the form ARIMA (1,1,0) x $(0,1,1)_{12}$, specifically expressed as

$$(1-\phi B)\nabla\nabla_{12}\, z_t = (1-\Theta B^{12})a_t$$

where

ϕ = non-seasonal autoregressive parameter
B = backward shift operator = $z_t - z_{t-1}$
∇ = difference operator
z_t = current value of the time series
Θ = seasonal moving average parameter, and
a_t = random shock (current residual or error).

This model fits the data relatively well for TDS salt balance, for both time spans between all stations except El Paso to Ft. Quitman. Also, again with the exception of El Paso to Ft. Quitman, this model adequately represents the behavior of most of the major ions in the river reaches between stations. There are some exceptions among the ions, stations, and the two time spans.

4.4.2 Salt Balance, Elephant Butte Dam to Courchesne Bridge

The conditions between Elephant Butte Dam and the Courchesne Bridge at El Paso are of particular interest to the author, so the results of the time series analyses are shown here as an illustrative example for the RGP. Once again, because of the time gap in the data, the two time periods had to be modeled separately. Figures 11-14 are graphs for the 1934-1963 time period, while Figures 15-18 are for 1979-1994. Complete modeling documentation of the salt balance for the river reach between these stations is enclosed in Appendix C.

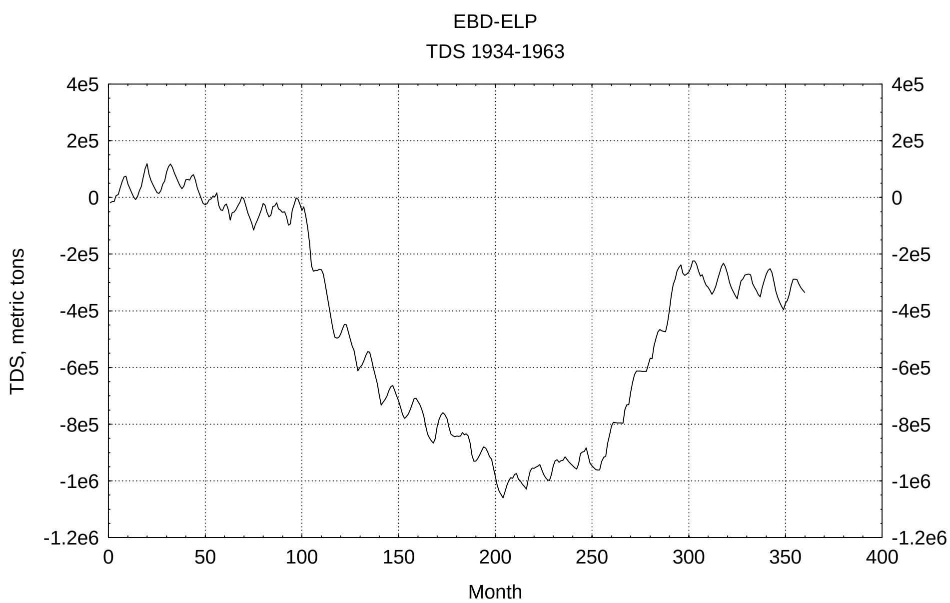


Figure 11. Elephant Butte-El Paso salt balance, 1934-1963

The TDS salt balance in the Rio Grande between Elephant Butte and El Paso at Courchesne Bridge for the years from 1934 to 1963 and 1979 to 1994 are plotted in Figures 11 and 15, respectively. These graphs illustrate the non-stationarity of the time series, that is that the mean and variance change with time. Figures 12 and 16 are correlograms or graphs of the autocorrelations for lags 1 through 30. These graphs illustrate the very strong correlation between the salt balance for the present month and each month for the previous 30 months. The correlations decrease going back in time, and even though the pattern is different for the time periods, the decrease is relatively slow. The failure of these correlograms to “die out rapidly” also is an indication of nonstationarity. Combining a consecutive difference at lag 1 and a seasonal difference at lag 12, for both time series, induced stationarity.

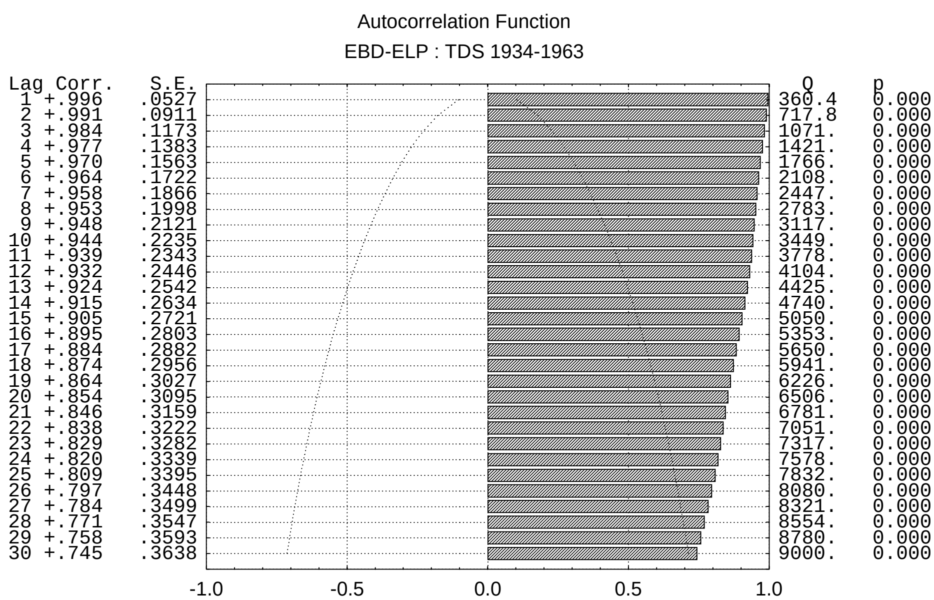


Figure 12. Autocorrelation function of raw data (EBD-ELP, 1934-1963)

A first order autoregressive filter along with a seasonal moving average operator then were applied, yielding models which met the diagnostic checks, as indicated by the residual plots in Figures 13 and 17 and the correlograms of the residuals in Figures 14 and 18.

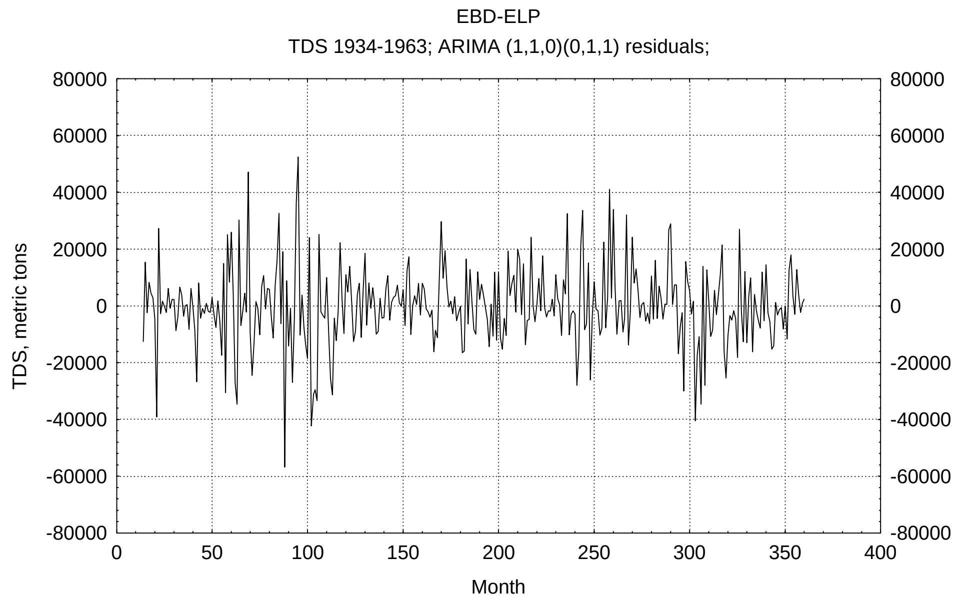


Figure 13. Time plot of the model residuals (EBD-ELP, 1934-1963)

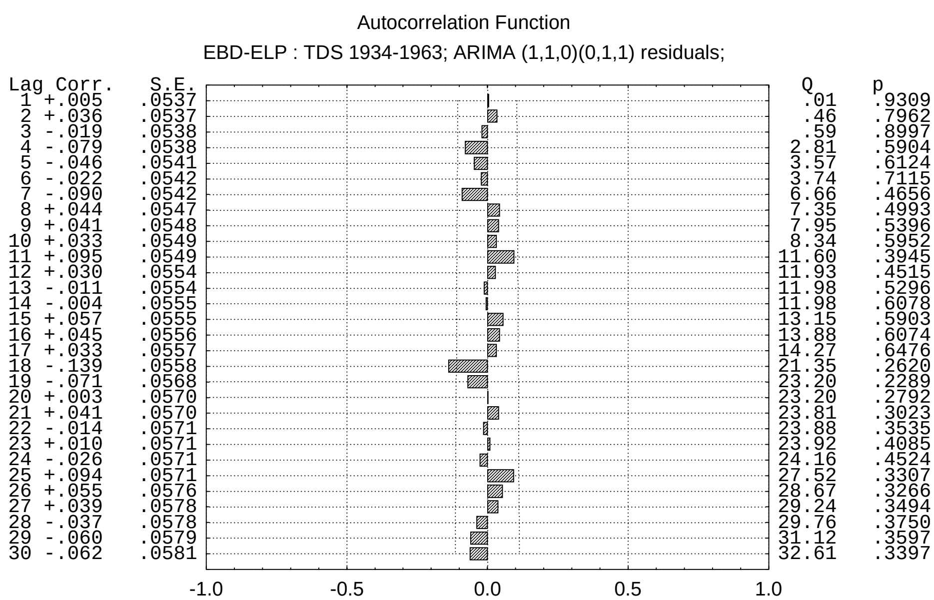


Figure 14. Autocorrelation function of the model residuals (EBD-ELP, 1934-1963)

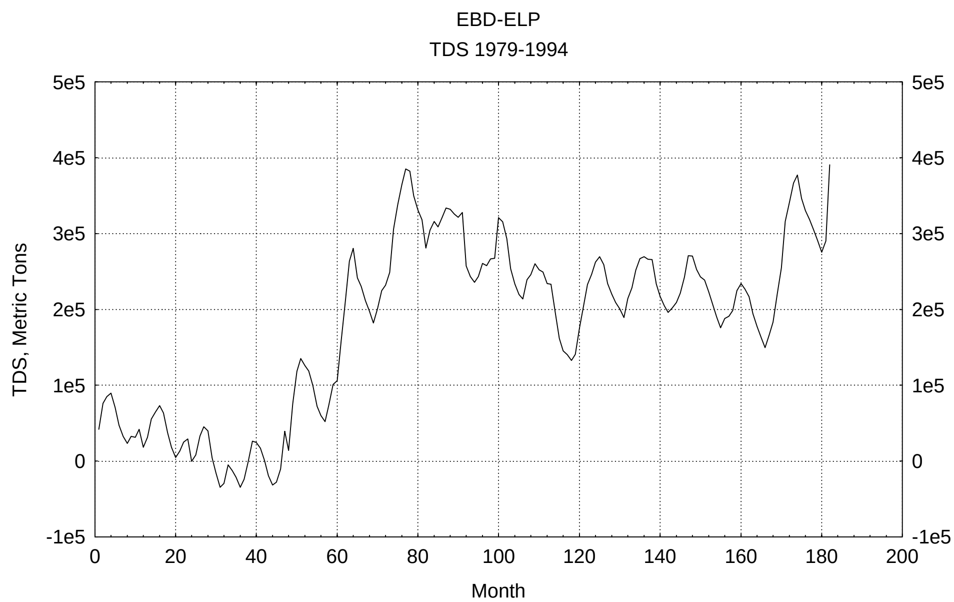


Figure 15. Time plot of raw data (EBD-ELP, 1979-1994)

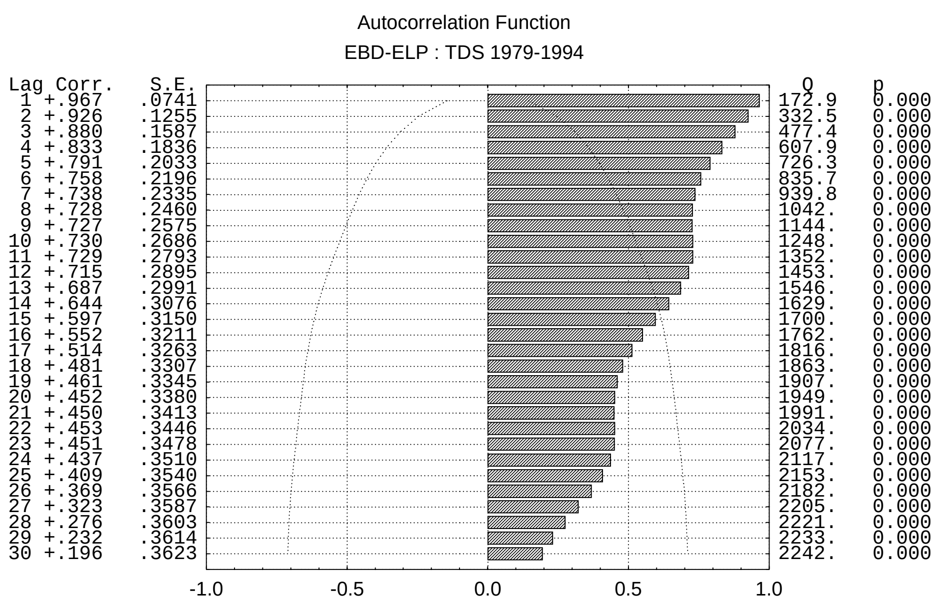


Figure 16. Autocorrelation function of raw data (EBD-ELP, 1979-1994)

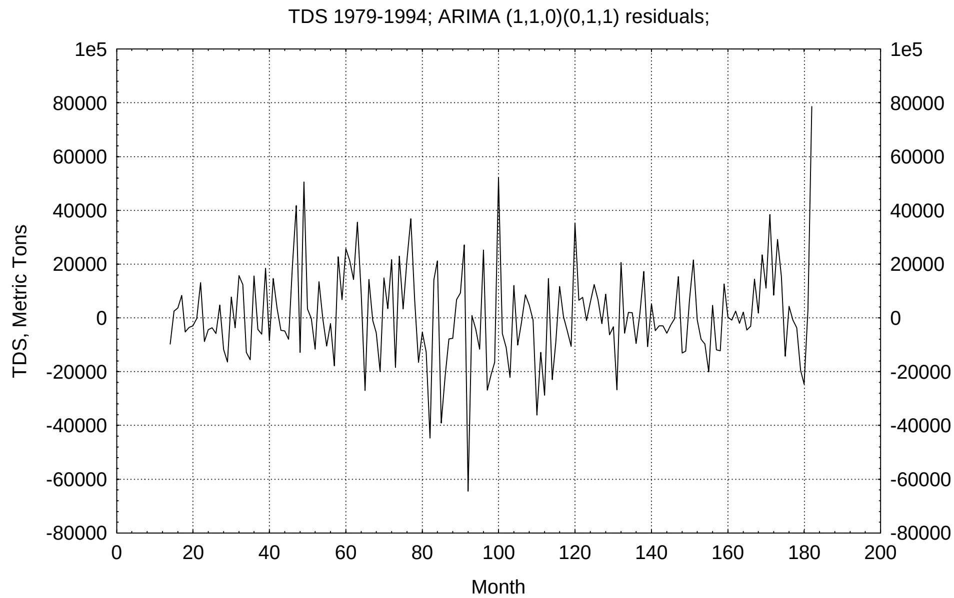


Figure 17. Time plot of the model residuals (EBD-ELP, 1979-1994)

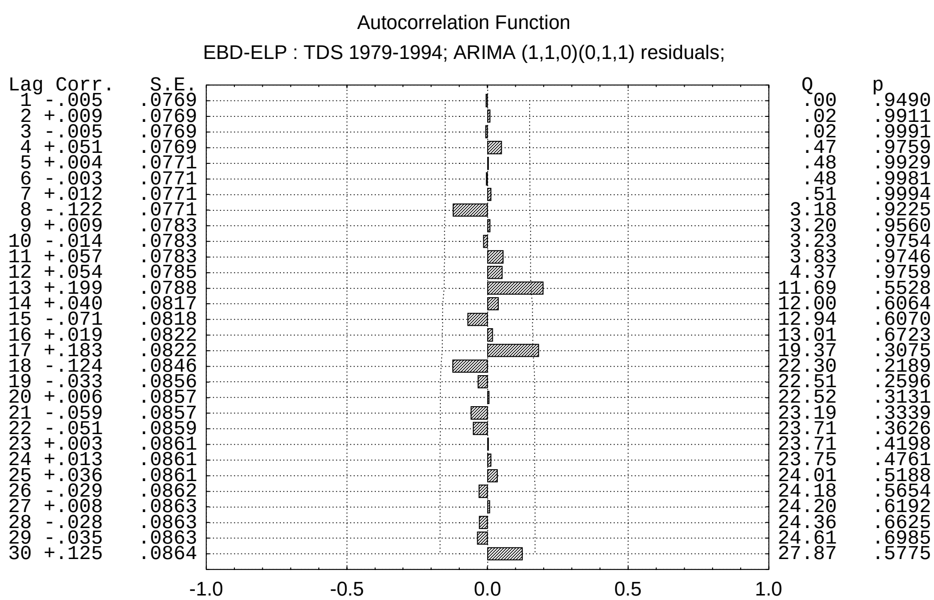


Figure 18. Autocorrelation function of the model residuals (EBD-ELP,1979-1994)

The ARIMA(1,1,0) x $(0,1,1)_{12}$ model fits both the time series from 1934 to1963 and from 1979 to 1994 for TDS. Even though the parameter values are different, as shown in Tables 9 and 10, the seasonal moving average parameter values overlap within the 95% confidence interval and all parameter values are statistically significant at $\alpha = .05$. The residuals show no significant autocorrelations through lag 30 and the mean for each is not statistically different from zero at $\alpha = .05$ level of significance, as shown in Tables 11 & 12. The variance for each appears to be relatively constant as the time plot of the residuals illustrates (see Appendix C).

Table 9. Parameter Estimates (EBD-ELP, 1934 – 1963)

Transformations: D(1),D(12) Model:(1,1,0)(0,1,1) Seasonal lag: 12 MS Residual=1971E5						
		Asympt.	Asympt.		Lower	Upper
	Param.	Std.Err.	t(345)	p	95% Conf	95% Conf
p(1)	0.5265	0.0466	11.2969	0.0000	0.4348	0.6182
Qs(1)	0.5666	0.0517	10.9572	0.0000	0.4649	0.6683

Table 10. Parameter Estimates (EBD-ELP, 1979-1994)

Transformations: D(1),D(12) Model:(1,1,0)(0,1,1) Seasonal lag: 12 MS Residual=3156E5						
		Asympt.	Asympt.		Lower	Upper
	Param.	Std.Err.	t(167)	p	95% Conf	95% Conf
p(1)	0.2146	0.0810	2.6497	0.0088	0.0547	0.3745
Qs(1)	0.7551	0.0676	11.1694	0.0000	0.6217	0.8886

Table 11. Descriptive Statistics (EBD-ELP, 1934-1963)

TDS Metric Tons	Mean	Std.Dv.	Confid. -95%	Confid. 95%	Minimum	Maximum	N
EBD-ELP	-401,749	365,652	-439649	-363850	-1,045,142	118,219	360
D(1),D(12)	-169	18,035	-2074	1735	-53,161	64,384	347
Model (1,1,0)(0,1,1)							
Residuals	-121	14,017	-1601	1359	-56,956	52,838	347
Forecasts	-401,756	372,455			-1,045,142	118,219	360

Table 12. Descriptive Statistics (EBD-ELP, 1979-1994)

TDS Metric Tons	Mean	Std.Dv.	Confid. -95%	Confid. 95%	Minimum	Maximum	N
EBD-ELP	179,521	114,725	162,741	196,301	-34,525	390,832	182
D(1),D(12)	867	20,662	-2,270	4,005	-68,923	65,634	169
Model (1,1,0)(0,1,1)							
Residuals	1,034	17,682	-1,651	3,719	-64,395	78,634	169
Forecasts	179,089	118,403	162,405	195,773	-34,525	385,421	182

Tables 13 & 14 contain the one step-ahead forecasts and 90% confidence limits for both time periods. Both models perform reasonably well. The deviation of the forecasts from the actual figures is, in general, relatively small.

The forecasts for the earlier time period were generated using parameter estimates based on the first 336 observations (January 1934- December 1961) and updating the parameter estimates each time a new observation became available. For example, after the forecasts were obtained using the 336 data points, the parameters of the same model specifications were re-estimated using 337 data points, and with this new set of estimates, new forecasts were generated. This process was repeated 24 times. Ninety percent or better of the observed values fall within the 90% confidence interval.

4.4.3 Salt Balance, Courchesne Bridge to Fort Quitman

An ARIMA model representing the salt balance in the Rio Grande meeting all the diagnostic checks could not be constructed. With multiple autoregressive seasonal and non-seasonal operators combined with seasonal and non-seasonal moving average filters, all significant at the .05 level, the Box & Ljung Q lack of fit statistics were higher than allowed. Significant autocorrelation remained in the residuals, even though the means were not statistically different from zero at 95% confidence and the variances were fairly constant.

Table 13. One step ahead forecast (EBD-ELP, 1934-1963)

Month	Forecast	Lower 90%	Upper 90%	Std.Err.	Observed	Residual	Deviation %
Jan-62	-195,755	-219,134	-172,376	14,175	-203,340	-7,586	3.73
Feb-62	-183,051	-206,404	-159,698	14,160	-171,941	11,110	-6.46
Mar-62	-143,302	-166,641	-119,963	14,151	-148,403	-5,101	3.44
Apr-62	-137,555	-160,863	-114,247	14,132	-122,792	14,763	-12.02
May-62	-106,336	-129,647	-83,025	14,134	-109,047	-2,711	2.49
Jun-62	-98,961	-122,238	-75,685	14,113	-103,833	-4,871	4.69
Jul-62	-103,412	-126,657	-80,167	14,094	-118,626	-15,214	12.83
Aug-62	-135,153	-158,404	-111,902	14,098	-149,571	-14,418	9.64
Sep-62	-185,491	-208,743	-162,238	14,099	-184,255	1,236	-0.67
Oct-62	-202,756	-225,974	-179,538	14,077	-206,115	-3,359	1.63
Nov-62	-220,583	-243,768	-197,399	14,057	-221,964	-1,381	0.62
Dec-62	-236,261	-259,411	-213,111	14,036	-236,767	-506	0.21
Jan-63	-240,749	-263,864	-217,634	14,015	-248,679	-7,930	3.19
Feb-63	-225,519	-248,611	-202,427	14,001	-229,434	-3,915	1.71
Mar-63	-209,405	-232,465	-186,345	13,982	-241,454	-32,049	13.27
Apr-63	-242,928	-266,134	-219,723	14,070	-223,221	19,708	-8.83
May-63	-211,824	-235,063	-188,586	14,090	-214,601	-2,777	1.29
Jun-63	-209,326	-232,531	-186,120	14,070	-228,427	-19,102	8.36
Jul-63	-244,626	-267,860	-221,392	14,088	-231,275	13,351	-5.77
Aug-63	-247,763	-270,993	-224,532	14,085	-225,346	22,417	-9.95
Sep-63	-241,315	-264,598	-218,032	14,117	-245,933	-4,618	1.88
Oct-63	-258,469	-281,721	-235,216	14,099	-258,250	218	-0.08
Nov-63	-268,292	-291,511	-245,074	14,078	-267,190	1,102	-0.41
Dec-63	-278,068	-301,253	-254,883	14,058	-275,535	2,533	-0.92

Table 14. One step ahead forecast (EBD-ELP, 1979-1994)

Month	Forecast	Lower 90%	Upper 90%	Std.Err.	Observed	Residual	Deviation %
Jun-92	212,256	184,056	240,456	17,049	224,883	12,627	5.61
Jul-92	233,690	205,534	261,845	17,022	233,953	263	0.11
Aug-92	227,564	199,506	255,622	16,964	226,717	-848	-0.37
Sep-92	214,204	186,242	242,167	16,906	216,760	2,555	1.18
Oct-92	196,172	168,302	224,041	16,849	194,196	-1,976	-1.02
Nov-92	175,206	147,430	202,982	16,793	177,416	2,210	1.25
Dec-92	167,141	139,457	194,826	16,738	162,602	-4,539	-2.79
Jan-93	152,726	125,127	180,325	16,686	149,666	-3,060	-2.04
Feb-93	152,124	124,614	179,635	16,632	166,591	14,467	8.68
Mar-93	181,540	154,052	209,028	16,619	183,285	1,745	0.95
Apr-93	196,592	169,193	223,991	16,565	220,039	23,448	10.66
May-93	243,789	216,301	271,278	16,619	254,832	11,043	4.33
Jun-93	277,661	250,222	305,100	16,589	316,081	38,420	12.16
Jul-93	332,416	304,596	360,236	16,820	340,821	8,406	2.47
Aug-93	337,588	309,834	365,341	16,779	366,792	29,204	7.96
Sep-93	362,031	334,099	389,962	16,887	377,447	15,417	4.08
Oct-93	360,798	332,882	388,715	16,878	346,521	-14,277	-4.12
Nov-93	326,278	298,387	354,170	16,863	330,540	4,262	1.29
Dec-93	319,325	291,514	347,135	16,814	318,474	-851	-0.27
Jan-94	308,438	280,713	336,162	16,762	304,797	-3,640	-1.19
Feb-94	310,640	282,996	338,283	16,713	291,116	-19,524	-6.71
Mar-94	299,924	272,250	327,599	16,731	275,370	-24,554	-8.92
Apr-94	287,458	259,687	315,229	16,790	290,405	2,947	1.01

5.0 SUMMARY AND CONCLUSIONS

TDS (mg/L) was determined to be EC_{25} (μS/cm)*0.66 (mg/L per μS/cm). The New Mexico portion of the RGP (including 10,880 acres of water righted land in the Texas portion of the Mesilla Valley) had a negative (good) salt balance before 1963. After 1980, it appears to be in a positive (bad) balance.

The Texas portion of the RGP had a positive balance before the mid 1980s. Excess flow in 1986 removed significant salt from the Project, and the balance has been more favorable since.

ARIMA models can be used for forecasting purposes for water quality management.

Continuing data collection is needed, to avoid gaps in data such as that occurring from 1964-1980.

Salt management planning is needed throughout the RGP, both for long-term agricultural sustainability and for managing instantaneous quality for municipal users.

APPENDICES

APPENDIX A

EL PASO ION/TDS RATIOS COMPARISON SUMMARY

January

Ion, mg/l	Mean	Std dev.	Lower 95%	Upper 95%
Calcium				
Actual	120	19	116	125
Calculated	127	38	118	137
Magnesium				
Actual	29	5	28	31
Calculated	31	9	29	33
Sodium				
Actual	353	144	317	389
Calculated	345	102	319	370
Carbonate				
Actual	144	19	139	149
Calculated	147	44	136	158
Sulfate				
Actual	511	157	472	551
Calculated	489	145	452	525
Chloride				
Actual	308	128	276	340
Calculated	316	94	292	339

February

Ion, mg/l	Mean	Std dev.	Lower 95%	Upper 95%
Calcium				
Actual	114	23	109	120
Calculated	123	52	110	136
Magnesium				
Actual	28	7	27	30
Calculated	29	12	26	33
Sodium				
Actual	347	178	303	392
Calculated	320	135	286	354
Carbonate				
Actual	137	24	131	143
Calculated	141	60	126	156
Sulfate				
Actual	496	205	444	547
Calculated	473	199	423	523
Chloride				
Actual	301	160	261	341
Calculated	288	121	258	319

March

Ion, mg/l	Mean	Std dev.	Lower 95%	Upper 95%
Calcium				
Actual	84	17	79	88
Calculated	86	25	80	92
Magnesium				
Actual	18	4	17	19
Calculated	19	5	17	20
Sodium				
Actual	139	51	126	152
Calculated	148	42	137	158
Carbonate				
Actual	99	9	96	101
Calculated	97	28	90	104
Sulfate				
Actual	242	78	223	262
Calculated	262	75	243	280
Chloride				
Actual	128	60	113	143
Calculated	134	38	124	143

April

Ion, mg/l	Mean	Std dev.	Lower 95%	Upper 95%
Calcium				
Actual	85	13	82	88
Calculated	88	15	84	92
Magnesium				
Actual	18	3	17	19
Calculated	19	3	18	20
Sodium				
Actual	141	29	133	148
Calculated	143	25	137	149
Carbonate				
Actual	104	9	102	106
Calculated	99	17	95	103
Sulfate				
Actual	256	57	241	270
Calculated	265	46	253	276
Chloride				
Actual	116	31	108	123
Calculated	123	22	118	129

May

Ion, mg/l	Mean	Std dev.	Lower 95%	Upper 95%
Calcium				
Actual	88	17	84	92
Calculated	94	44	83	106
Magnesium				
Actual	19	5	18	21
Calculated	21	10	19	24
Sodium				
Actual	173	121	142	203
Calculated	159	75	140	178
Carbonate				
Actual	108	15	104	112
Calculated	108	50	95	120
Sulfate				
Actual	291	141	256	327
Calculated	292	137	258	326
Chloride				
Actual	142	104	116	168
Calculated	136	64	120	152

June

Ion, mg/l	Mean	Std dev.	Lower 95%	Upper 95%
Calcium				
Actual	81	11	78	84
Calculated	81	17	76	85
Magnesium				
Actual	17	3	16	18
Calculated	17	4	17	18
Sodium				
Actual	131	34	122	139
Calculated	126	26	119	132
Carbonate				
Actual	103	7	101	105
Calculated	89	18	85	94
Sulfate				
Actual	239	58	225	254
Calculated	237	49	225	249
Chloride				
Actual	103	33	95	111
Calculated	105	22	99	110

July

Ion, mg/l	Mean	Std dev.	Lower 95%	Upper 95%
Calcium				
Actual	78	10	75	80
Calculated	76	13	73	79
Magnesium				
Actual	16	3	16	17
Calculated	17	3	16	17
Sodium				
Actual	124	25	118	131
Calculated	120	20	115	125
Carbonate				
Actual	100	8	98	102
Calculated	93	16	89	97
Sulfate				
Actual	224	43	214	235
Calculated	223	37	214	232
Chloride				
Actual	97	24	91	103
Calculated	99	17	95	103

August

Ion, mg/l	Mean	Std dev.	Lower 95%	Upper 95%
Calcium				
Actual	78	10	76	81
Calculated	79	14	75	82
Magnesium				
Actual	16	3	16	17
Calculated	17	3	16	17
Sodium				
Actual	128	30	121	136
Calculated	120	21	115	126
Carbonate				
Actual	102	10	99	104
Calculated	96	17	92	100
Sulfate				
Actual	229	45	218	241
Calculated	224	39	214	234
Chloride				
Actual	103	27	96	110
Calculated	101	18	97	105

September

Ion, mg/l	Mean	Std dev.	Lower 95%	Upper 95%
Calcium				
Actual	90	14	86	93
Calculated	92	19	87	97
Magnesium				
Actual	19	3	18	20
Calculated	20	4	19	21
Sodium				
Actual	161	43	151	172
Calculated	154	31	147	162
Carbonate				
Actual	109	14	106	113
Calculated	107	22	102	113
Sulfate				
Actual	281	65	265	298
Calculated	275	56	260	289
Chloride				
Actual	135	40	125	145
Calculated	134	27	127	141

October

Ion, mg/l	Mean	Std dev.	Lower 95%	Upper 95%
Calcium				
Actual	112	23	106	118
Calculated	115	36	106	124
Magnesium				
Actual	26	5	25	28
Calculated	27	9	25	29
Sodium				
Actual	280	118	250	310
Calculated	272	85	250	293
Carbonate				
Actual	133	22	127	139
Calculated	132	41	122	143
Sulfate				
Actual	433	146	396	470
Calculated	414	130	382	447
Chloride				
Actual	242	105	216	269
Calculated	247	77	228	267

November

Ion, mg/l	Mean	Std dev.	Lower 95%	Upper 95%
Calcium				
Actual	124	16	120	128
Calculated	130	41	120	140
Magnesium				
Actual	30	5	28	31
Calculated	31	10	28	33
Sodium				
Actual	335	150	297	373
Calculated	323	101	298	349
Carbonate				
Actual	147	16	143	151
Calculated	150	47	138	162
Sulfate				
Actual	497	153	459	536
Calculated	476	149	438	514
Chloride				
Actual	292	144	256	329
Calculated	294	92	271	318

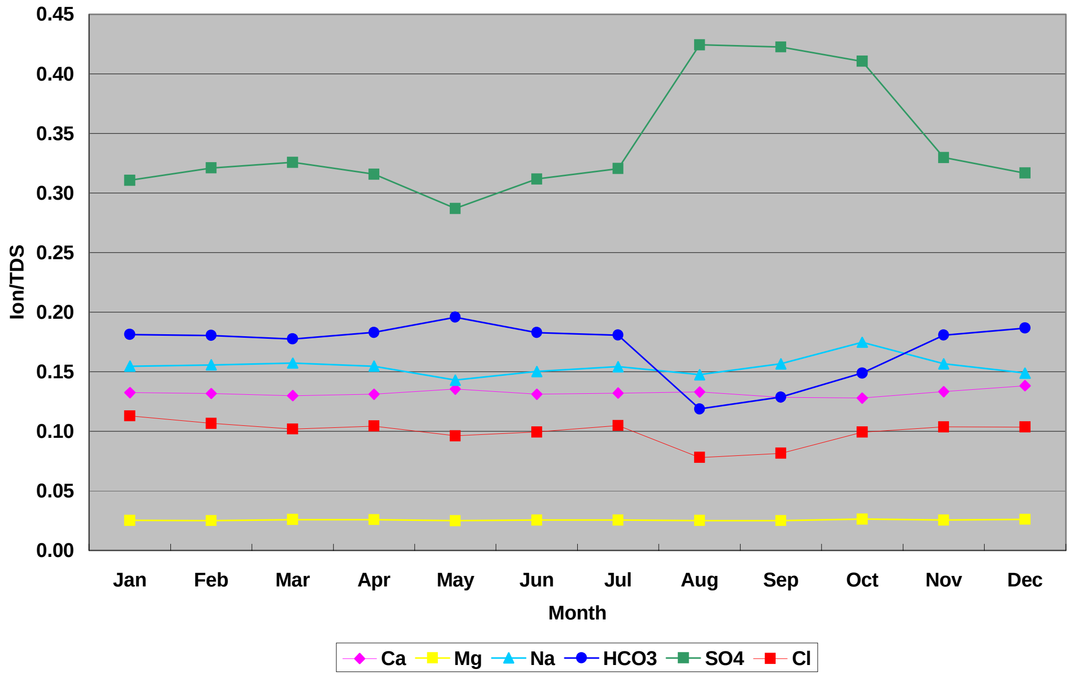
December

Ion, mg/l	Mean	Std dev.	Lower 95%	Upper 95%
Calcium				
Actual	124	19	119	129
Calculated	132	41	122	143
Magnesium				
Actual	30	5	28	31
Calculated	31	10	29	34
Sodium				
Actual	345	149	307	382
Calculated	326	101	301	352
Carbonate				
Actual	149	16	145	153
Calculated	154	48	142	166
Sulfate				
Actual	503	157	463	543
Calculated	477	148	440	515
Chloride				
Actual	299	137	265	334
Calculated	298	93	275	321

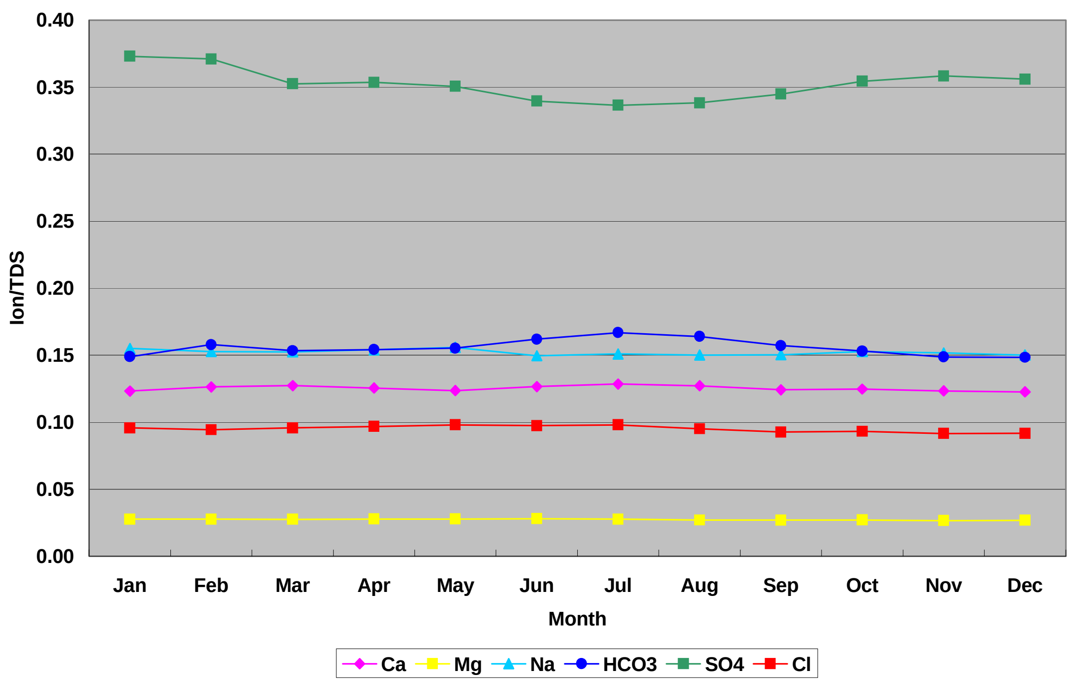
APPENDIX B

SEASONAL VARIATION OF ION/TDS RATIOS GRAPHS

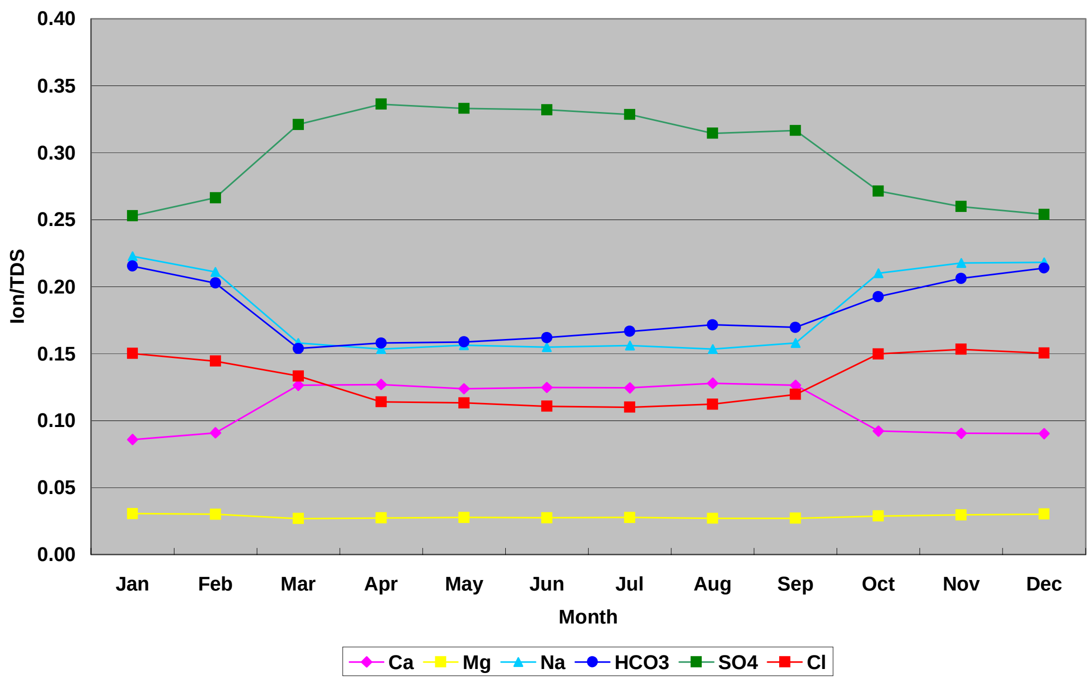
Seasonal variation of ion to TDS ratios at San Marcial, New Mexico



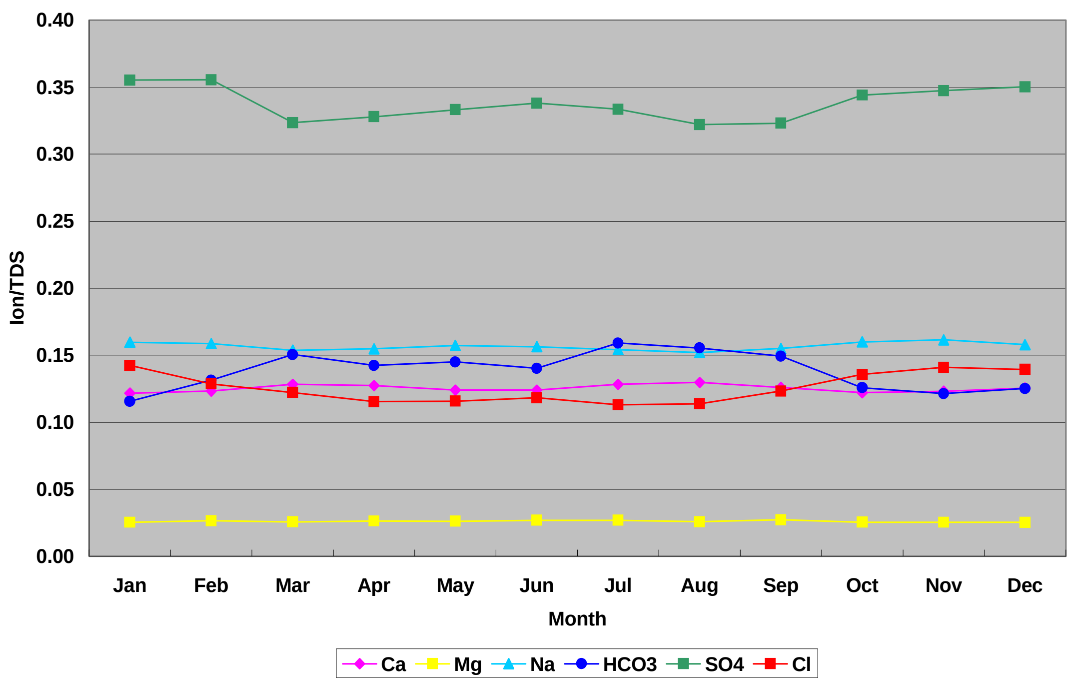
Seasonal variation of ion to TDS ratios at Elephant Butte Dam, New Mexico



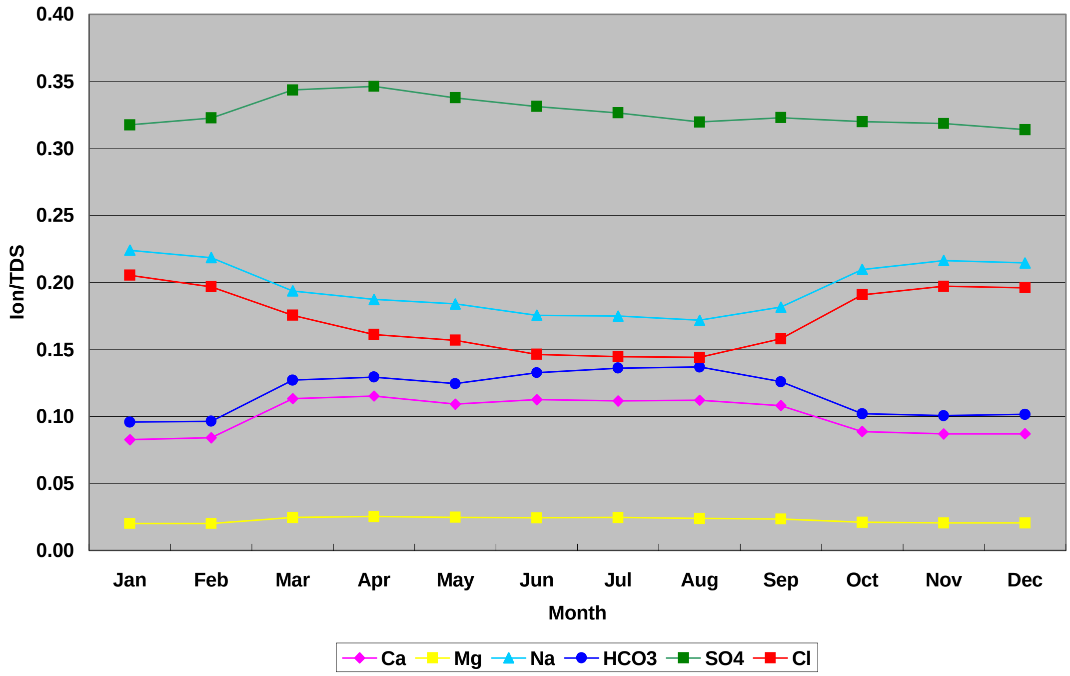
Seasonal variation of ion to TDS ratios in the Rio Grande below Caballo Dam, New Mexico



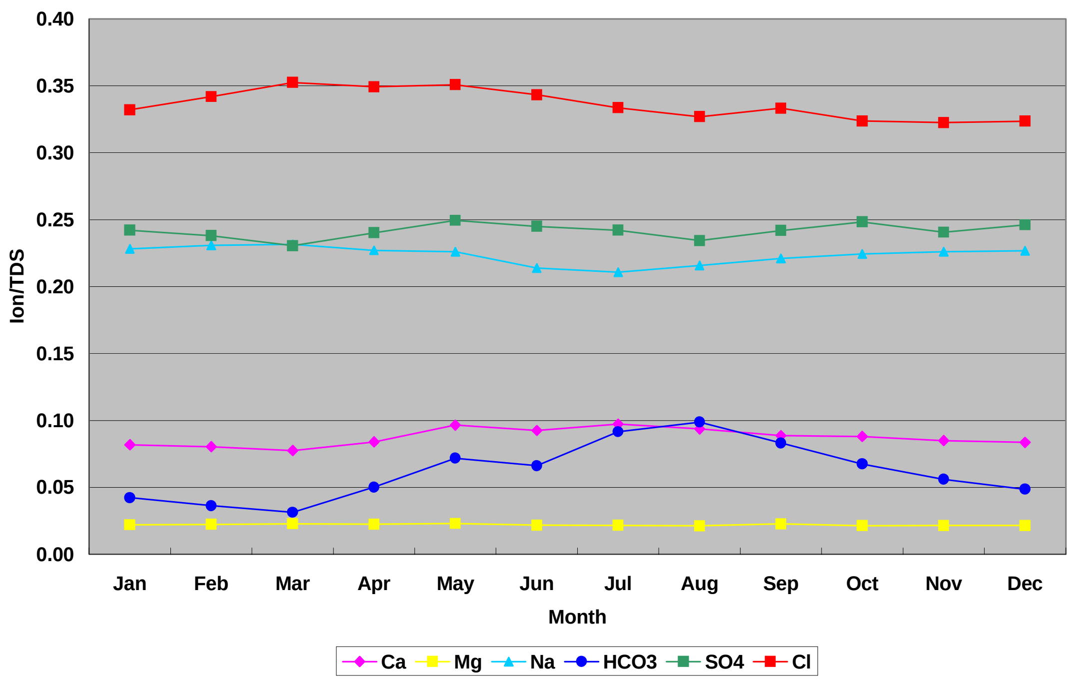
Seasonal variation in ion to TDS ratios in the Rio Grande above Leasburg Dam, New Mexico



Seasonal variation in ion to TDS ratios in the Rio Grande at Courchesne Bridge, Texas

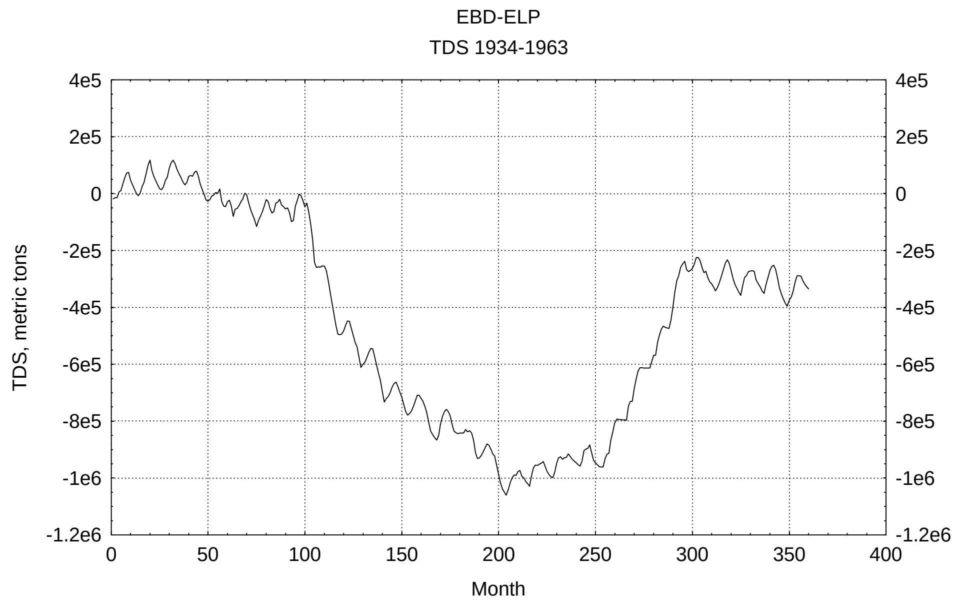


Seasonal variation in ion to TDS ratios in the Rio Grande at Ft. Quitman, Texas

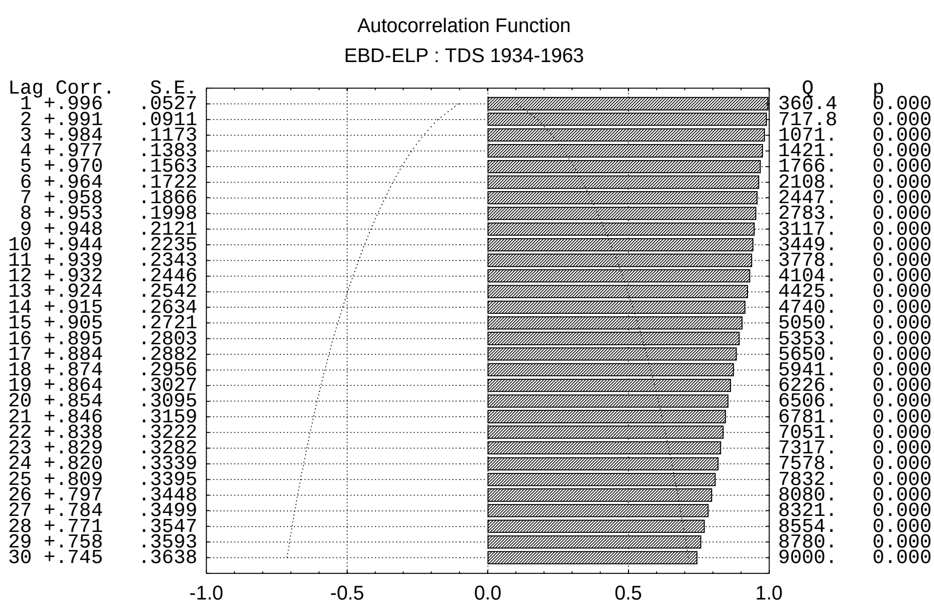


APPENDIX C

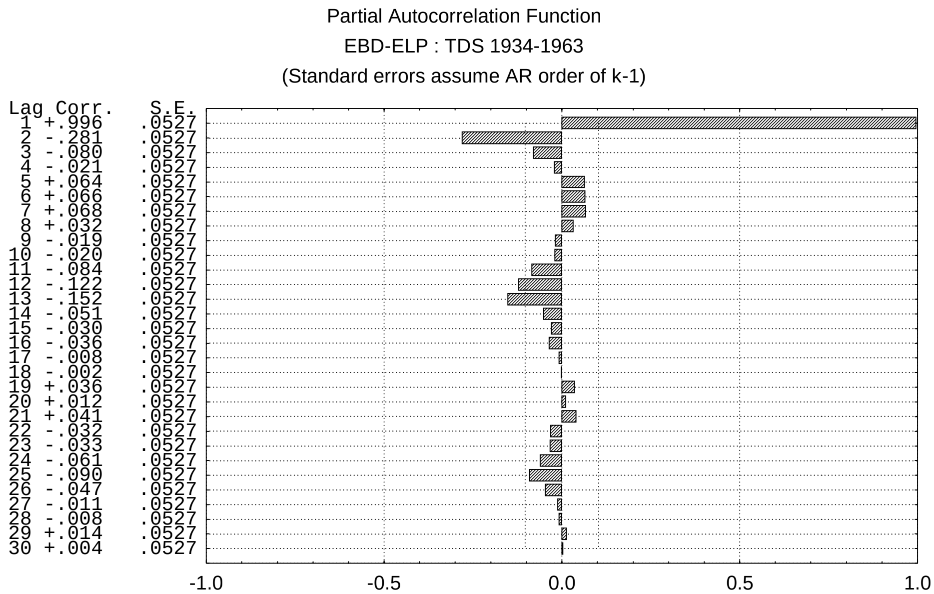
ARIMA MODELS DOCUMENTATION



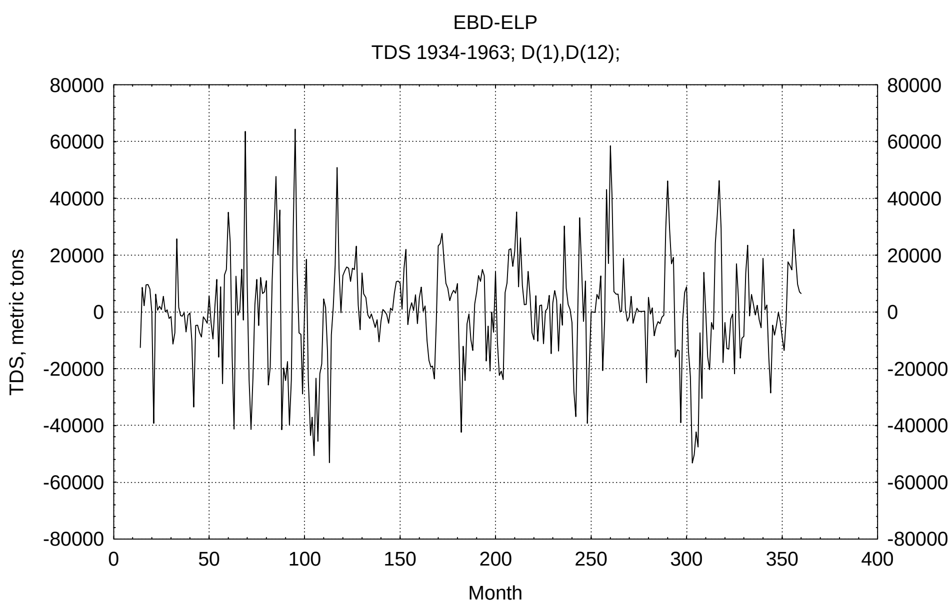
Time plot of raw data (EBD-ELP, 1934-1963)



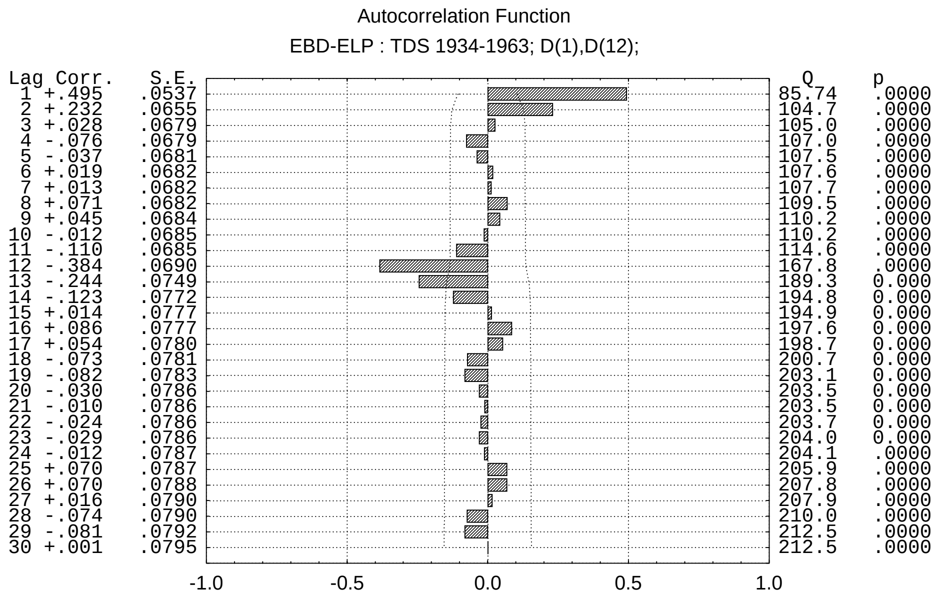
Autocorrelation function of raw data (EBD-ELP, 1934-1963)



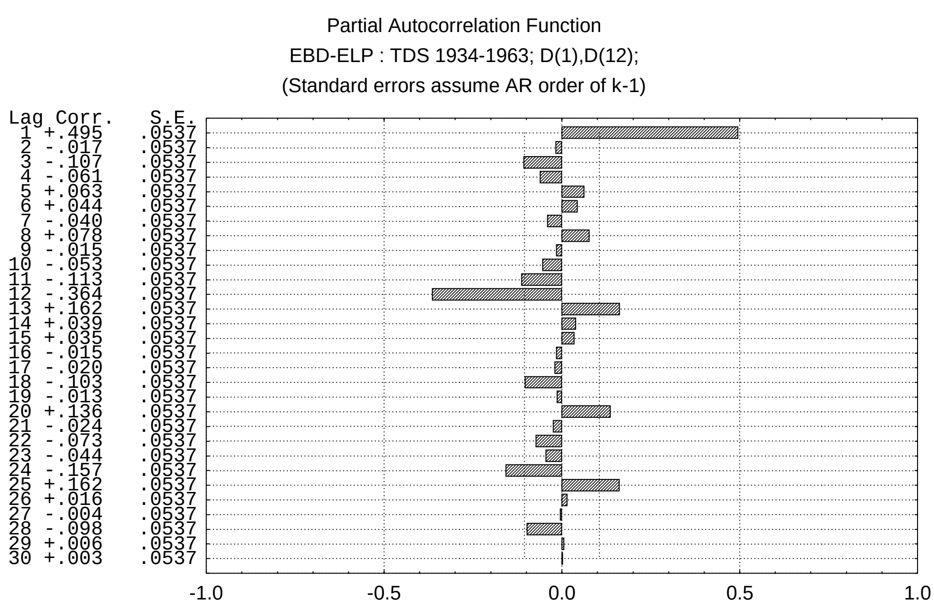
Partial Autocorrelation of raw data (EBD-ELP, 1934-1963)



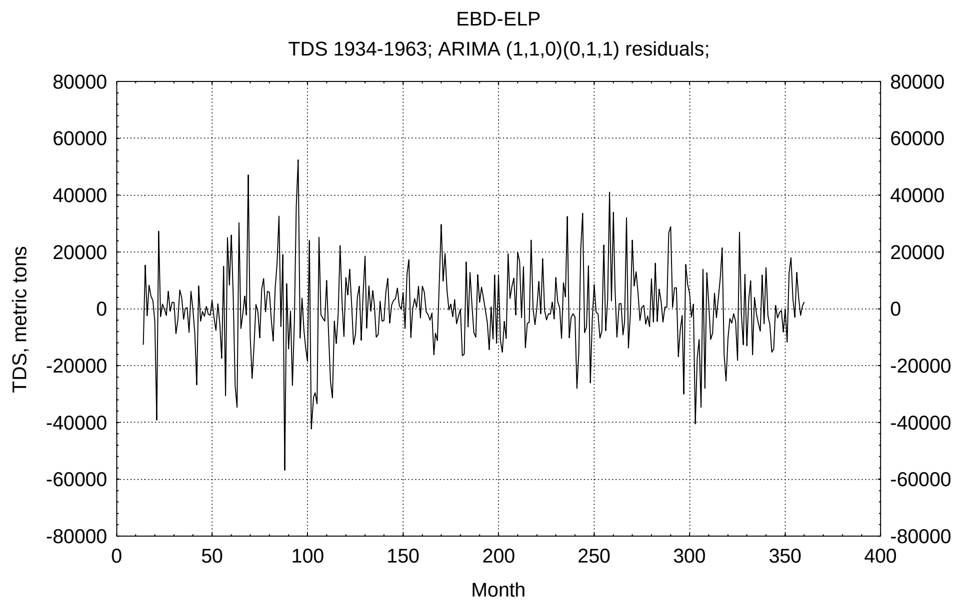
Time Plot of series after consecutive and seasonal differencing (EBD-ELP, 1934-1963)



Autocorrelation of the differenced data (EBD-ELP, 1934-1963)



Partial autocorrelation of the differenced data (EBD-ELP, 1934-1963)

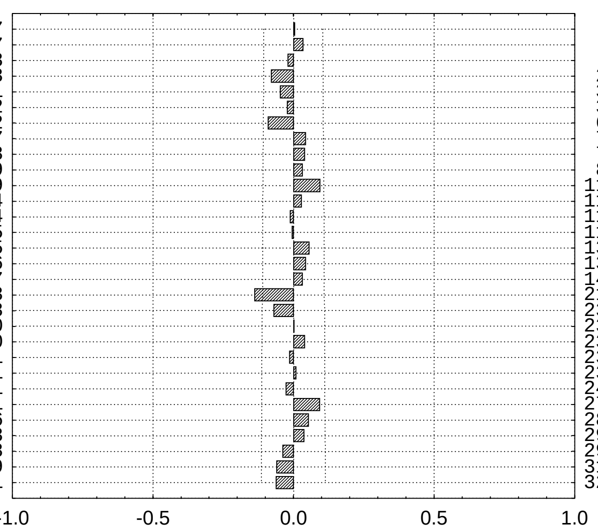


Time plot of the model residuals (EBD-ELP, 1934-1963)

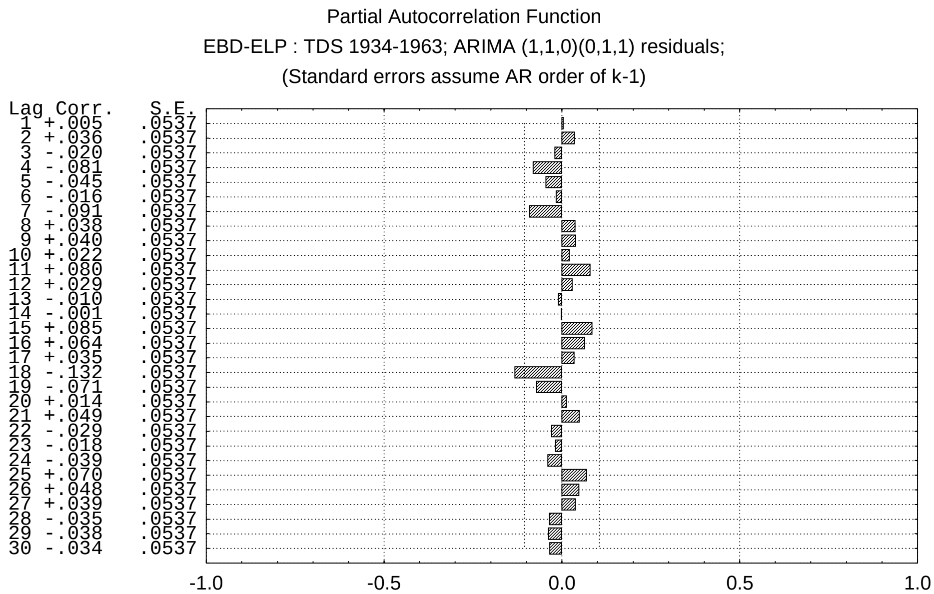
Autocorrelation Function

EBD-ELP : TDS 1934-1963; ARIMA (1,1,0)(0,1,1) residuals;

Lag	Corr.	S.E.	Q	p
1	+.005	.0537	.01	.9309
2	+.036	.0537	.46	.7962
3	-.019	.0538	.59	.8997
4	-.079	.0538	2.81	.5904
5	-.046	.0541	3.57	.6124
6	-.022	.0542	3.74	.7115
7	-.090	.0542	6.66	.4656
8	+.044	.0547	7.35	.4993
9	+.041	.0548	7.95	.5396
10	+.033	.0549	8.34	.5952
11	+.095	.0549	11.60	.3945
12	+.030	.0554	11.93	.4515
13	-.011	.0554	11.98	.5296
14	-.004	.0555	11.98	.6078
15	+.057	.0555	13.15	.5903
16	+.045	.0556	13.88	.6074
17	+.033	.0557	14.27	.6476
18	-.139	.0558	21.35	.2620
19	-.071	.0568	23.20	.2289
20	+.003	.0570	23.20	.2792
21	+.041	.0570	23.81	.3023
22	-.014	.0571	23.88	.3535
23	+.010	.0571	23.92	.4085
24	-.026	.0571	24.16	.4524
25	+.094	.0571	27.52	.3307
26	+.055	.0576	28.67	.3266
27	+.039	.0578	29.24	.3494
28	-.037	.0578	29.76	.3750
29	-.060	.0579	31.12	.3597
30	-.062	.0581	32.61	.3397



Autocorrelation function of the model residuals (EBD-ELP, 1934-1963)



Partial autocorrelation of the model residuals (EBD-ELP, 1934-1963)

Parameter Estimates (EBD-ELP, 1934-1963)

Transformations: D(1),D(12) Model:(1,1,0)(0,1,1) Seasonal lag: 12 MS Residual=1970E5						
		Asympt.	Asympt.		Lower	Upper
	Param.	Std.Err.	t(345)	p	95% Conf	95% Conf
p(1)	0.5390	0.0460	11.7142	0.0000	0.4485	0.6295
Qs(1)	0.5881	0.0500	11.7588	0.0000	0.4897	0.6865

Parameter Correlations (EBD-ELP, 1934-1963)

Parameter	p(1)	Qs(1)
p(1)	1	0.1799
Qs(1)	0.1799	1

Parameter Covariances (EBD-ELP, 1934-1963)

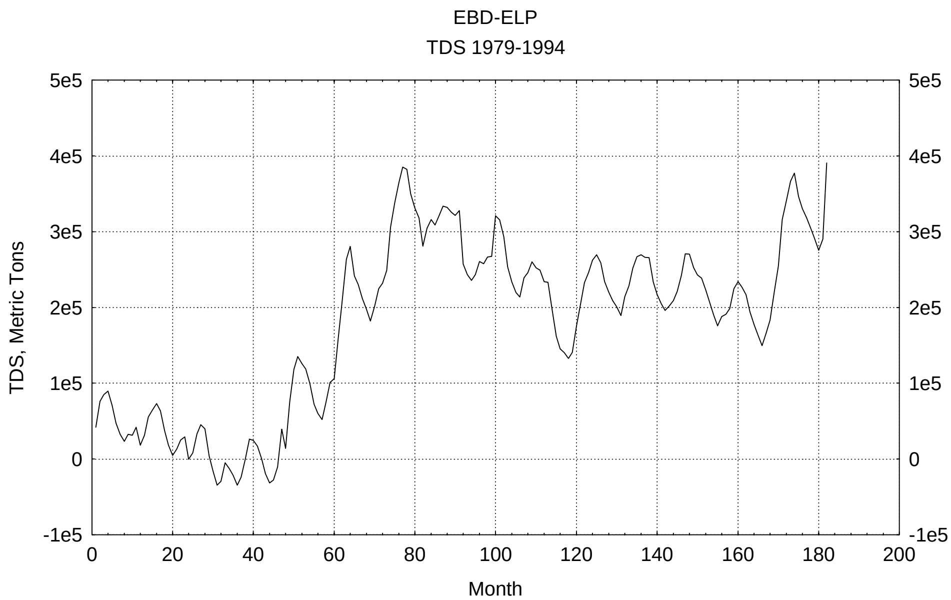
Parameter	p(1)	Qs(1)
p(1)	0.0022	0.0004
Qs(1)	0.0004	0.0027

Descriptive statistics (EBD-ELP, 1934-1963)

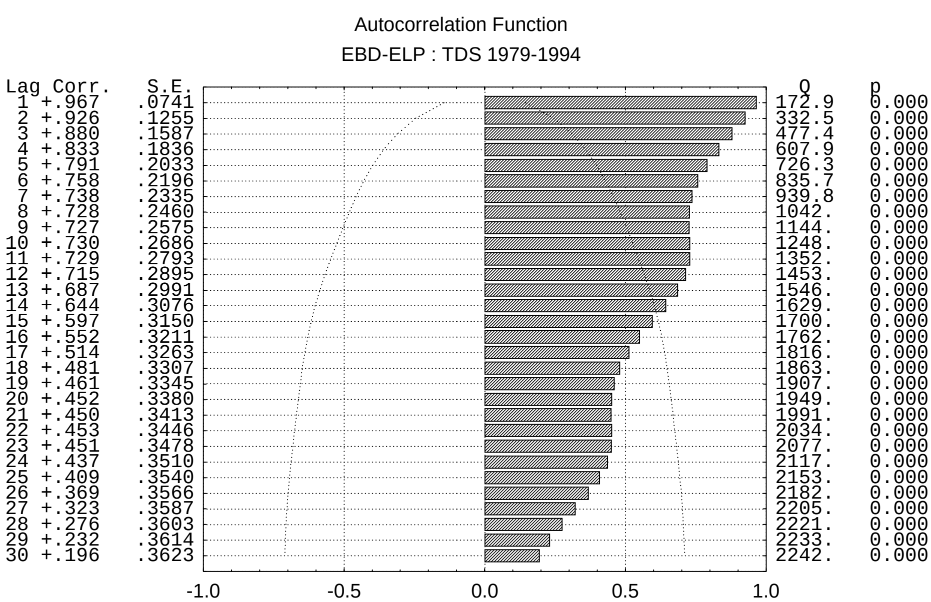
TDS Metric Tons	Mean	Std.Dv.	Confid. -95%	Confid. 95%	Minimum	Maximum	N
EBD-ELP	-401,749	365,652	-439649	-363850	-1,045,142	118,219	360
D(1),D(12)	-169	18,035	-2074	1735	-53,161	64,384	347
Model (1,1,0)(0,1,1)							
Residuals	-121	14,017	-1601	1359	-56,956	52,838	347
Forecasts	-401,756	372,455			-1,045,142	118,219	360

One step ahead forecast (EBD-ELP, 1934-1963)

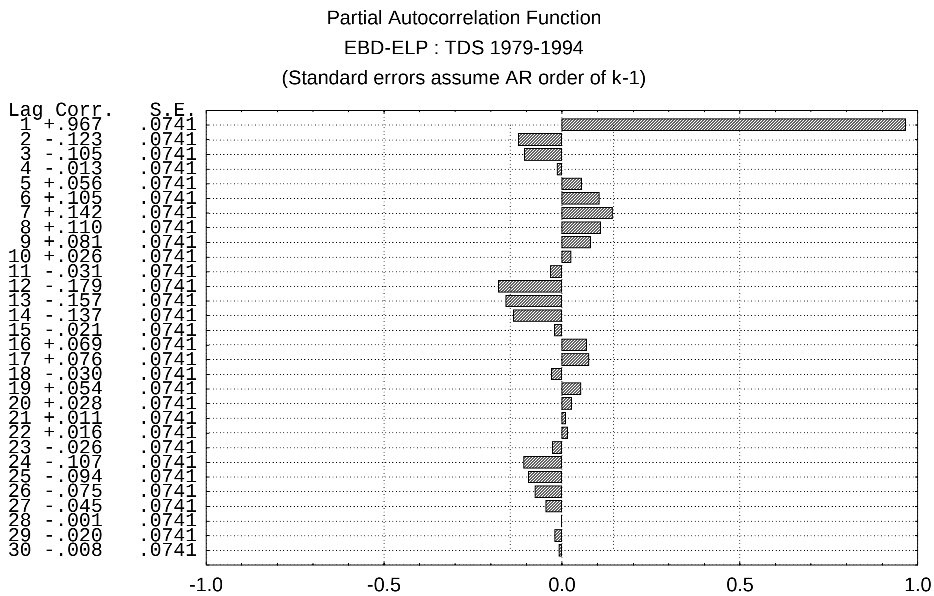
Month	Forecast	Lower 90%	Upper 90%	Std.Err.	Observed	Residual	Deviation %
Jan-62	-195,755	-219,134	-172,376	14,175	-203,340	-7,586	3.73
Feb-62	-183,051	-206,404	-159,698	14,160	-171,941	11,110	-6.46
Mar-62	-143,302	-166,641	-119,963	14,151	-148,403	-5,101	3.44
Apr-62	-137,555	-160,863	-114,247	14,132	-122,792	14,763	-12.02
May-62	-106,336	-129,647	-83,025	14,134	-109,047	-2,711	2.49
Jun-62	-98,961	-122,238	-75,685	14,113	-103,833	-4,871	4.69
Jul-62	-103,412	-126,657	-80,167	14,094	-118,626	-15,214	12.83
Aug-62	-135,153	-158,404	-111,902	14,098	-149,571	-14,418	9.64
Sep-62	-185,491	-208,743	-162,238	14,099	-184,255	1,236	-0.67
Oct-62	-202,756	-225,974	-179,538	14,077	-206,115	-3,359	1.63
Nov-62	-220,583	-243,768	-197,399	14,057	-221,964	-1,381	0.62
Dec-62	-236,261	-259,411	-213,111	14,036	-236,767	-506	0.21
Jan-63	-240,749	-263,864	-217,634	14,015	-248,679	-7,930	3.19
Feb-63	-225,519	-248,611	-202,427	14,001	-229,434	-3,915	1.71
Mar-63	-209,405	-232,465	-186,345	13,982	-241,454	-32,049	13.27
Apr-63	-242,928	-266,134	-219,723	14,070	-223,221	19,708	-8.83
May-63	-211,824	-235,063	-188,586	14,090	-214,601	-2,777	1.29
Jun-63	-209,326	-232,531	-186,120	14,070	-228,427	-19,102	8.36
Jul-63	-244,626	-267,860	-221,392	14,088	-231,275	13,351	-5.77
Aug-63	-247,763	-270,993	-224,532	14,085	-225,346	22,417	-9.95
Sep-63	-241,315	-264,598	-218,032	14,117	-245,933	-4,618	1.88
Oct-63	-258,469	-281,721	-235,216	14,099	-258,250	218	-0.08
Nov-63	-268,292	-291,511	-245,074	14,078	-267,190	1,102	-0.41
Dec-63	-278,068	-301,253	-254,883	14,058	-275,535	2,533	-0.92



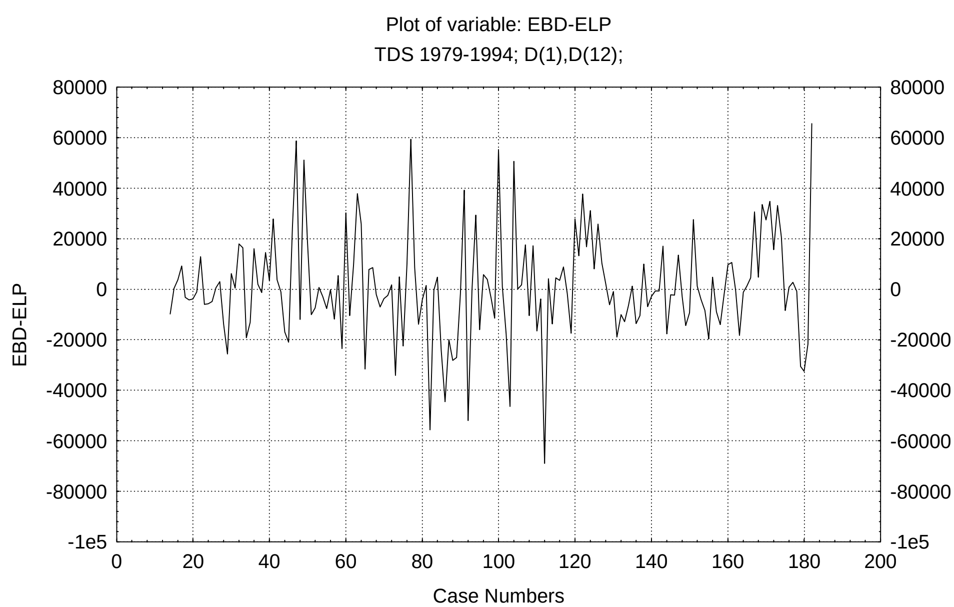
Time plot of raw data (EBD-ELP, 1979-1994)



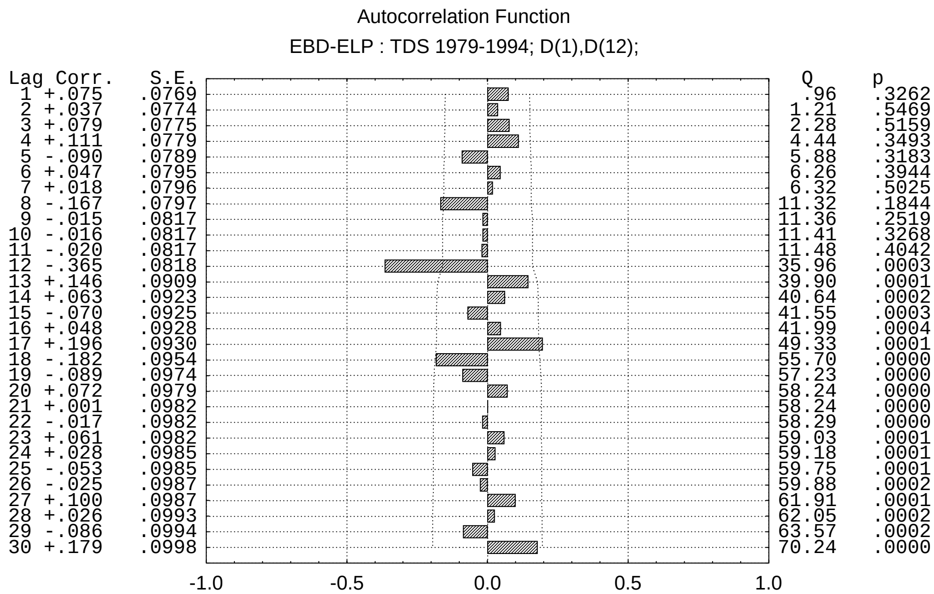
Autocorrelation function of raw data (EBD-ELP, 1979-1994)



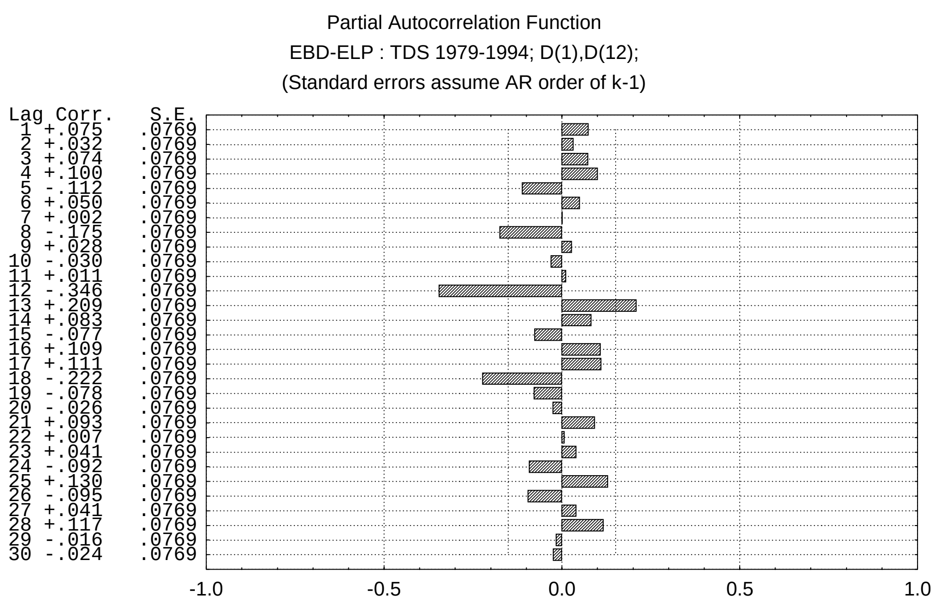
Partial autocorrelation of raw data (EBD-ELP, 1979-1994)



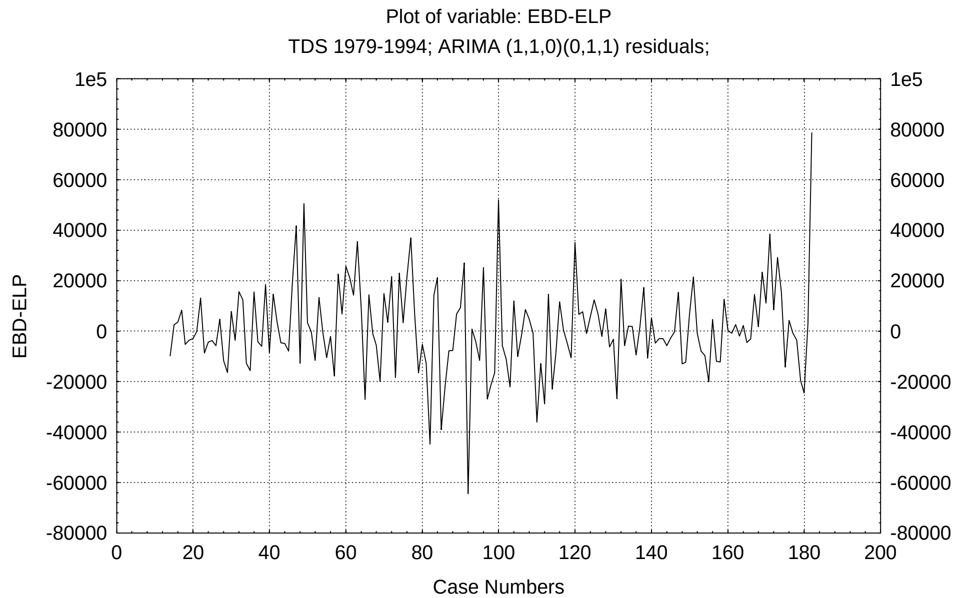
Time plot of the data after consecutive and seasonal differencing (EBD-ELP, 1979-1994)



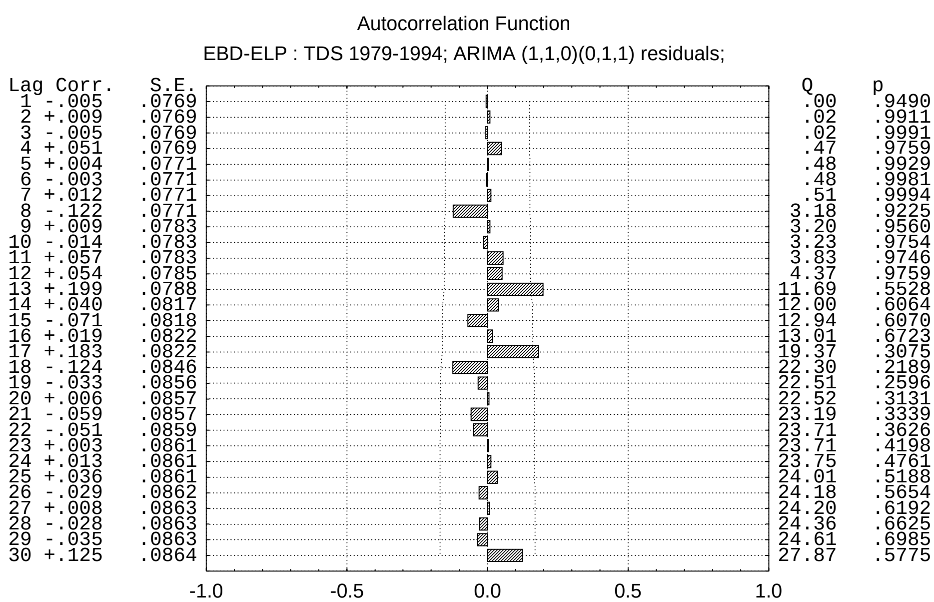
Autocorrelation function of the differenced data (EBD-ELP, 1979-1994)



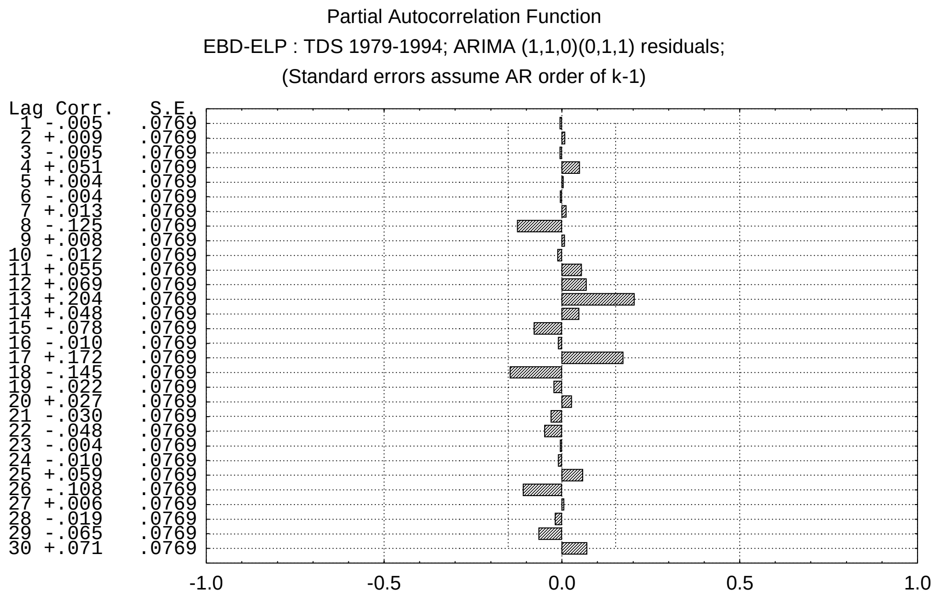
Partial autocorrelation function of the differenced data (EBD-ELP, 1979-1994)



Time plot of the model residuals (EBD-ELP, 1979-1994)



Autocorrelation function of the model residuals (EBD-ELP, 1979-1994)



Partial autocorrelation function of the model residuals (EBD-ELP, 1979-1994)

Parameter estimates (EBD-ELP, 1979-1994)

Input: EBD-ELP : TDS 1979-1994 (ebd-elp tds 94.sta) Transformations: D(1),D(12) Model:(1,1,0)(0,1,1) Seasonal lag: 12 MS Residual=3156E5						
		Asympt.	Asympt.		Lower	Upper
	Param.	Std.Err.	t(167)	p	95% Conf	95% Conf
p(1)	0.2146	0.0810	2.6497	0.0088	0.0547	0.3745
Qs(1)	0.7551	0.0676	11.1694	0.0000	0.6217	0.8886

Parameter correlations (EBD-ELP, 1979-1994)

Parameter	p(1)	Qs(1)
p(1)	1	0.097858
Qs(1)	0.097858	1

Parameter covariances (EBD-ELP, 1979-1994**)**

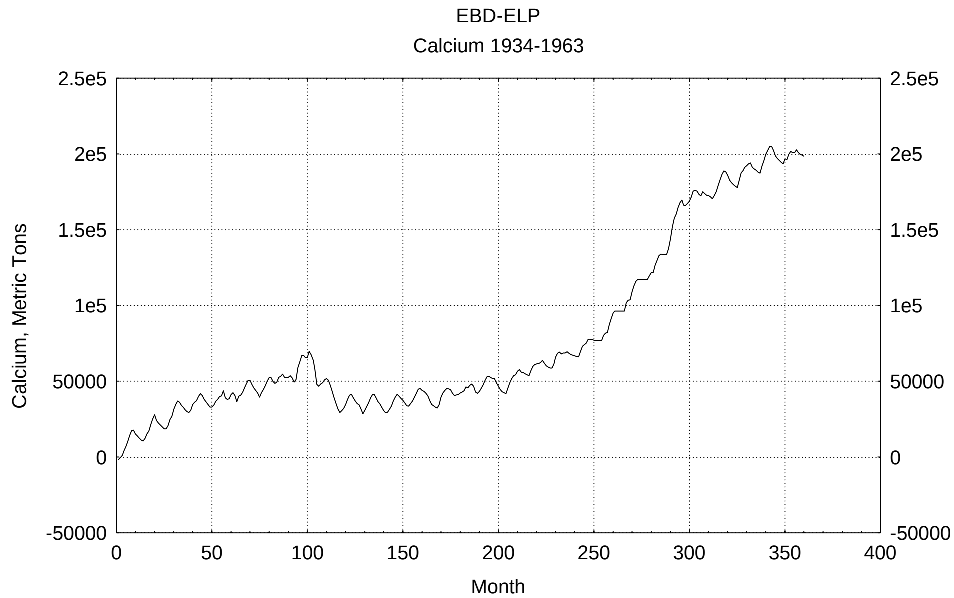
Parameter	p(1)	Qs(1)
p(1)	0.006558	0.000536
Qs(1)	0.000536	0.004571

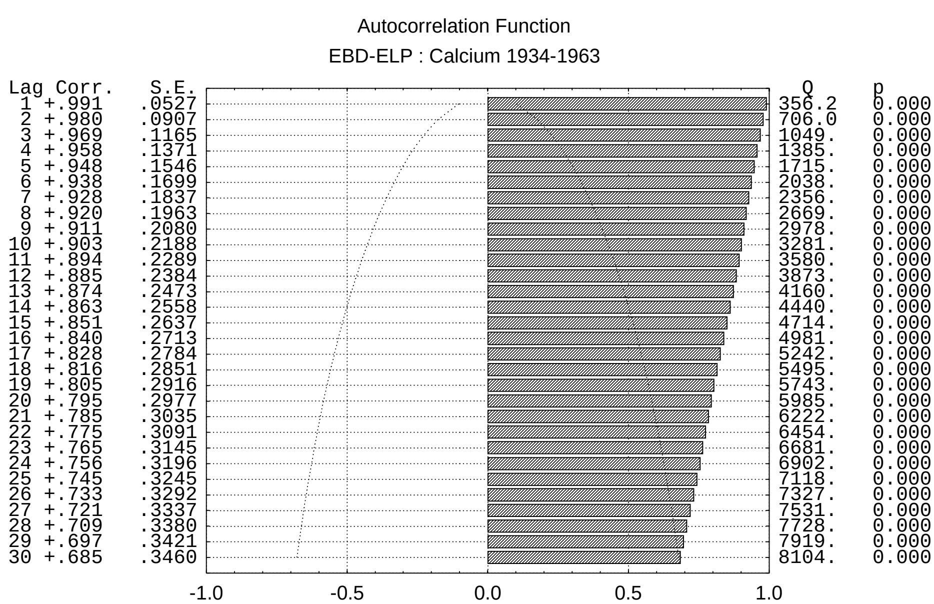
Descriptive statistics (EBD-ELP, 1979-1994)

TDS Metric Tons	Mean	Std.Dv.	Confid. -95%	Confid. 95%	Minimum	Maximum	N
EBD-ELP	179,521	114,725	162,741	196,301	-34,525	390,832	182
D(1),D(12)	867	20,662	-2,270	4,005	-68,923	65,634	169
Model (1,1,0)(0,1,1)							
Residuals	1,034	17,682	-1,651	3,719	-64,395	78,634	169
Forecasts	179,089	118,403	162,405	195,773	-34,525	385,421	182

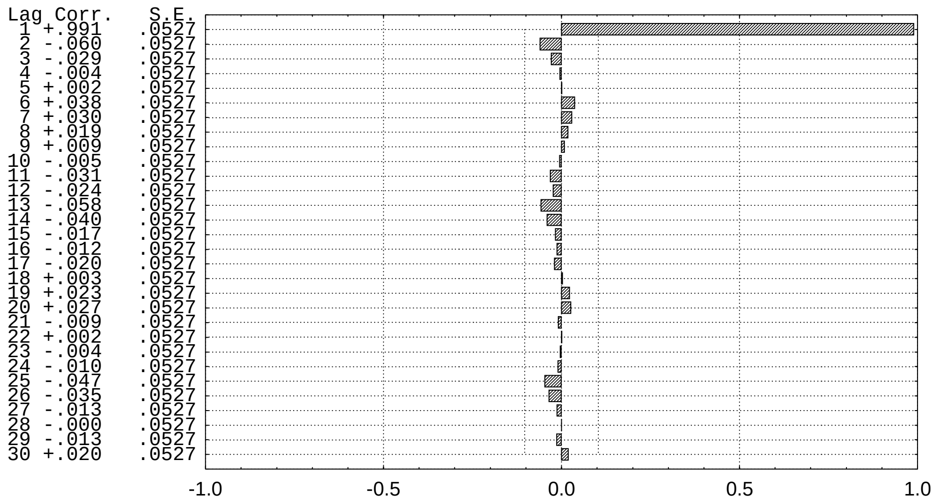
One step ahead forecast (EBD-ELP, 1979-1994)

Month	Forecast	Lower 90%	Upper 90%	Std.Err.	Observed	Residual	Deviation %
Jun-92	212,256	184,056	240,456	17,049	224,883	12,627	5.61
Jul-92	233,690	205,534	261,845	17,022	233,953	263	0.11
Aug-92	227,564	199,506	255,622	16,964	226,717	-848	-0.37
Sep-92	214,204	186,242	242,167	16,906	216,760	2,555	1.18
Oct-92	196,172	168,302	224,041	16,849	194,196	-1,976	-1.02
Nov-92	175,206	147,430	202,982	16,793	177,416	2,210	1.25
Dec-92	167,141	139,457	194,826	16,738	162,602	-4,539	-2.79
Jan-93	152,726	125,127	180,325	16,686	149,666	-3,060	-2.04
Feb-93	152,124	124,614	179,635	16,632	166,591	14,467	8.68
Mar-93	181,540	154,052	209,028	16,619	183,285	1,745	0.95
Apr-93	196,592	169,193	223,991	16,565	220,039	23,448	10.66
May-93	243,789	216,301	271,278	16,619	254,832	11,043	4.33
Jun-93	277,661	250,222	305,100	16,589	316,081	38,420	12.16
Jul-93	332,416	304,596	360,236	16,820	340,821	8,406	2.47
Aug-93	337,588	309,834	365,341	16,779	366,792	29,204	7.96
Sep-93	362,031	334,099	389,962	16,887	377,447	15,417	4.08
Oct-93	360,798	332,882	388,715	16,878	346,521	-14,277	-4.12
Nov-93	326,278	298,387	354,170	16,863	330,540	4,262	1.29
Dec-93	319,325	291,514	347,135	16,814	318,474	-851	-0.27
Jan-94	308,438	280,713	336,162	16,762	304,797	-3,640	-1.19
Feb-94	310,640	282,996	338,283	16,713	291,116	-19,524	-6.71
Mar-94	299,924	272,250	327,599	16,731	275,370	-24,554	-8.92
Apr-94	287,458	259,687	315,229	16,790	290,405	2,947	1.01

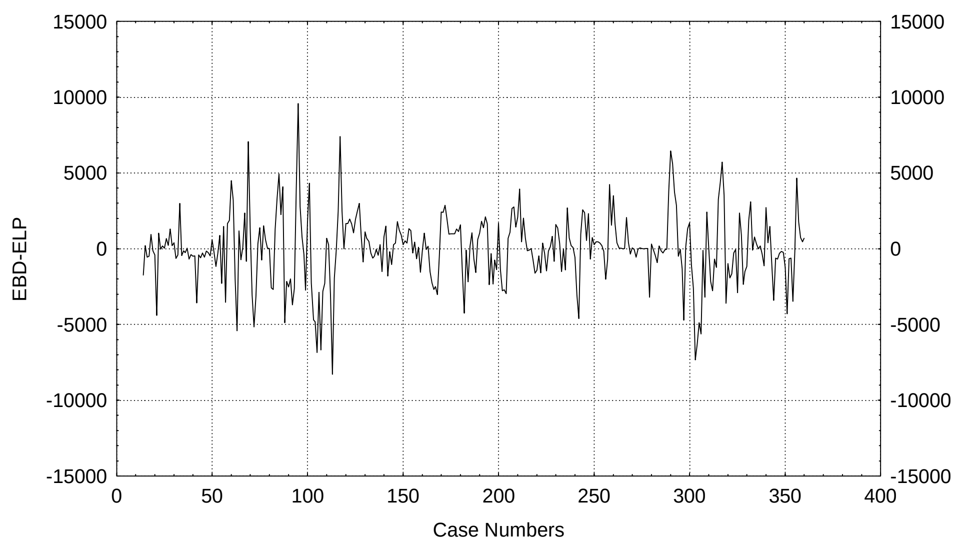

EBD-ELP
Calcium 1934-1963
Calcium, Metric Tons
Month
2.5e5
2e5
1.5e5
1e5
50000
0
-50000
0
50
100
150
200
250
300
350
400


Autocorrelation Function
EBD-ELP : Calcium 1934-1963
Lag Corr. S.E. Q p
1 +.991 .0527 356.2 0.000
2 +.980 .0907 706.0 0.000
3 +.969 .1165 1049. 0.000
4 +.958 .1371 1385. 0.000
5 +.948 .1546 1715. 0.000
6 +.938 .1699 2038. 0.000
7 +.928 .1837 2356. 0.000
8 +.920 .1963 2669. 0.000
9 +.911 .2080 2978. 0.000
10 +.903 .2188 3281. 0.000
11 +.894 .2289 3580. 0.000
12 +.885 .2384 3873. 0.000
13 +.874 .2473 4160. 0.000
14 +.863 .2558 4440. 0.000
15 +.851 .2637 4714. 0.000
16 +.840 .2713 4981. 0.000
17 +.828 .2784 5242. 0.000
18 +.816 .2851 5495. 0.000
19 +.805 .2916 5743. 0.000
20 +.795 .2977 5985. 0.000
21 +.785 .3035 6222. 0.000
22 +.775 .3091 6454. 0.000
23 +.765 .3145 6681. 0.000
24 +.756 .3196 6902. 0.000
25 +.745 .3245 7118. 0.000
26 +.733 .3292 7327. 0.000
27 +.721 .3337 7531. 0.000
28 +.709 .3380 7728. 0.000
29 +.697 .3421 7919. 0.000
30 +.685 .3460 8104. 0.000
-1.0
-0.5
0.0
0.5
1.0

Partial Autocorrelation Function
EBD-ELP : Calcium 1934-1963
(Standard errors assume AR order of k-1)

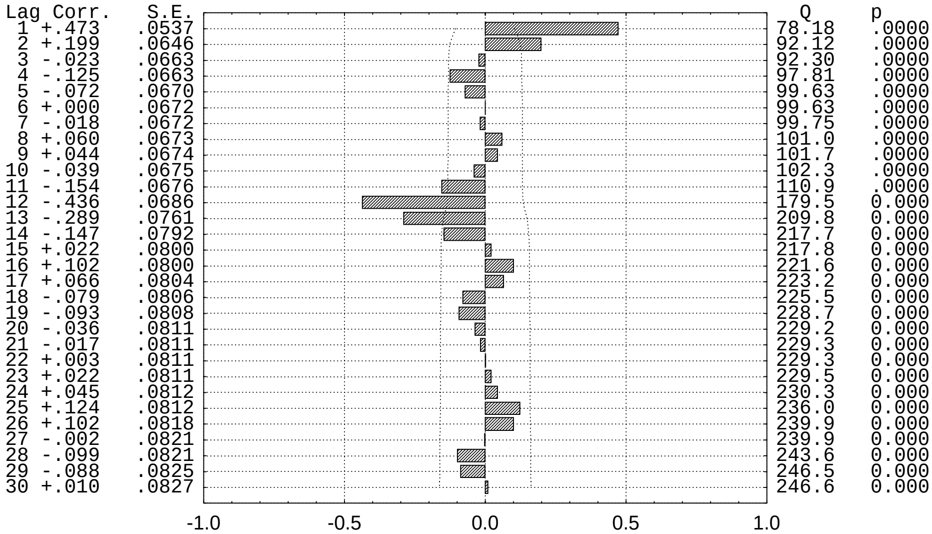


Plot of variable: EBD-ELP
Calcium 1934-1963; D(1),D(12);



Autocorrelation Function

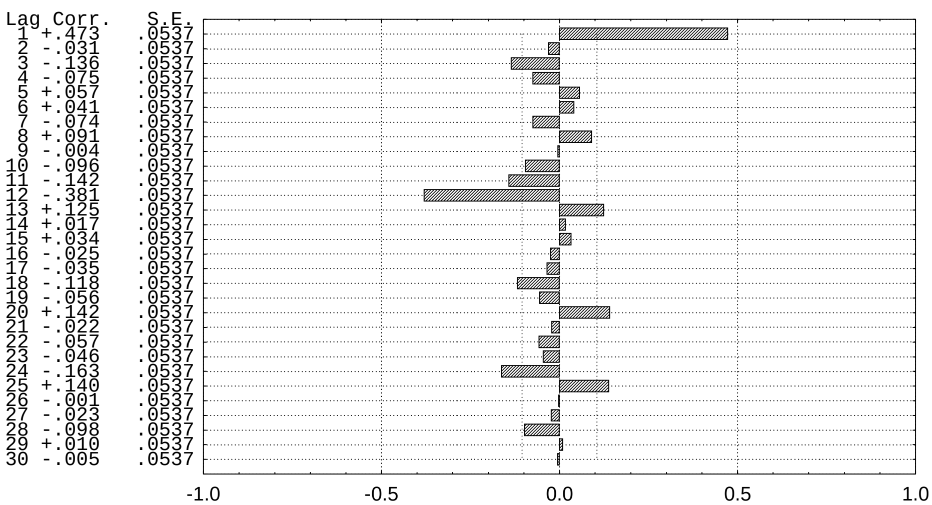
EBD-ELP : Calcium 1934-1963; D(1),D(12);



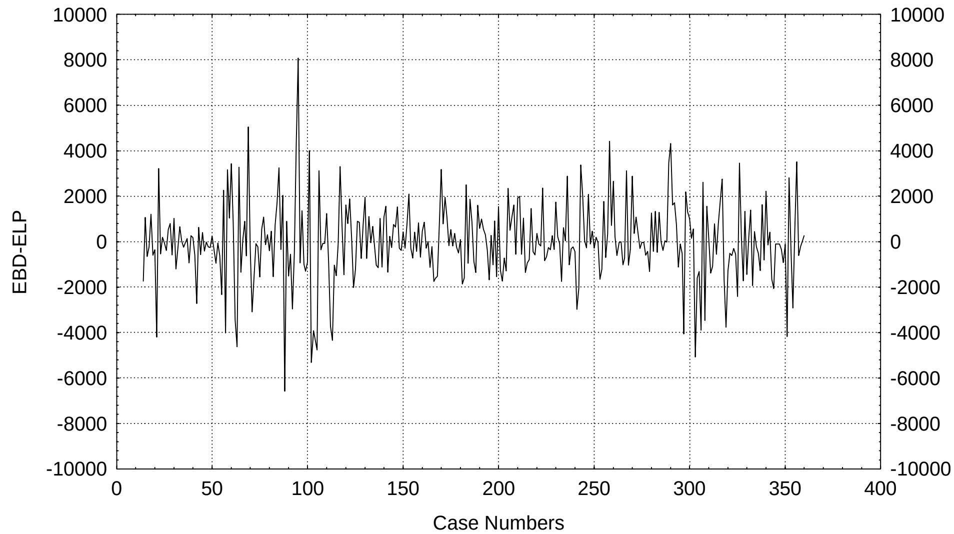
Partial Autocorrelation Function

EBD-ELP : Calcium 1934-1963; D(1),D(12);

(Standard errors assume AR order of k-1)

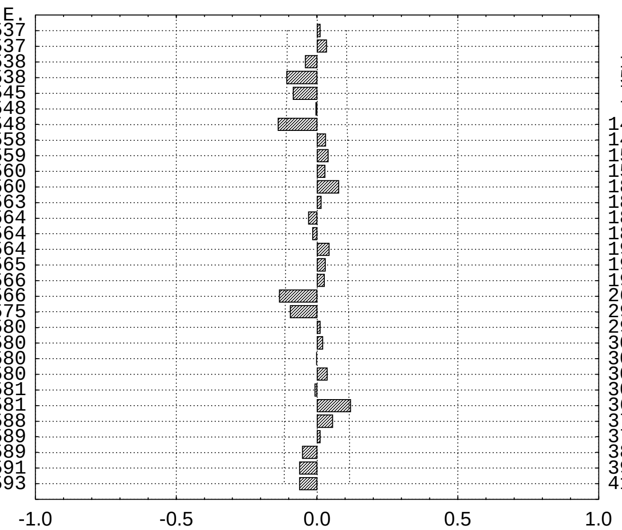


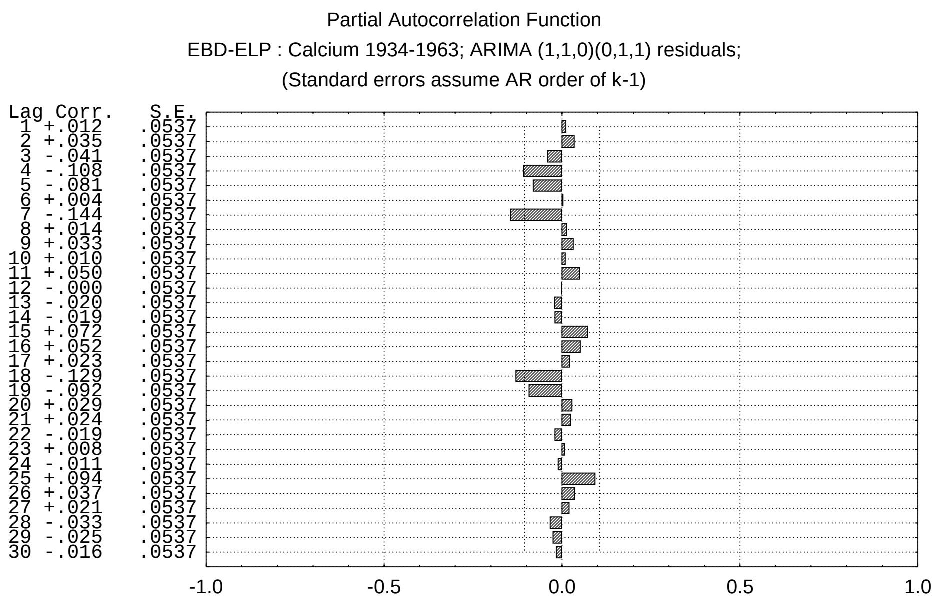
Plot of variable: EBD-ELP
Calcium 1934-1963; ARIMA (1,1,0)(0,1,1) residuals;



Autocorrelation Function
EBD-ELP : Calcium 1934-1963; ARIMA (1,1,0)(0,1,1) residuals;

Lag	Corr.	S.E.	Q	p
1	+.012	.0537	.05	.8217
2	+.035	.0537	.49	.7847
3	-.040	.0538	1.06	.7862
4	-.107	.0538	5.10	.2770
5	-.085	.0545	7.66	.1761
6	-.004	.0548	7.66	.2639
7	-.139	.0548	14.52	.0426
8	+.031	.0558	14.88	.0616
9	+.041	.0559	15.47	.0790
10	+.030	.0560	15.79	.1058
11	+.079	.0560	18.03	.0810
12	+.015	.0563	18.11	.1125
13	-.029	.0564	18.42	.1423
14	-.014	.0564	18.49	.1853
15	+.044	.0564	19.21	.2044
16	+.031	.0565	19.56	.2409
17	+.027	.0566	19.83	.2830
18	-.134	.0566	26.48	.0894
19	-.096	.0575	29.85	.0538
20	+.012	.0580	29.90	.0716
21	+.022	.0580	30.07	.0906
22	-.001	.0580	30.07	.1168
23	+.038	.0580	30.60	.1331
24	-.007	.0581	30.62	.1653
25	+.121	.0581	36.13	.0698
26	+.057	.0588	37.34	.0697
27	+.012	.0589	37.40	.0880
28	-.052	.0589	38.42	.0909
29	-.063	.0591	39.92	.0855
30	-.063	.0593	41.42	.0803





Parameter estimates (Calcium, EBD-ELP, 1934-1963)

Transformations: D(1),D(12) Model:(1,1,0)(0,1,1) Seasonal lag: 12 MS Residual=3005E3						
		Asympt.	Asympt.		Lower	Upper
	Param.	Std.Err.	t(345)	p	95% Conf	95% Conf
p(1)	0.4953	0.0474	10.4557	0.0000	0.4021	0.5885
Qs(1)	0.6047	0.0487	12.4190	0.0000	0.5089	0.7005

Parameter correlations (Calcium, EBD-ELP, 1934-1963)

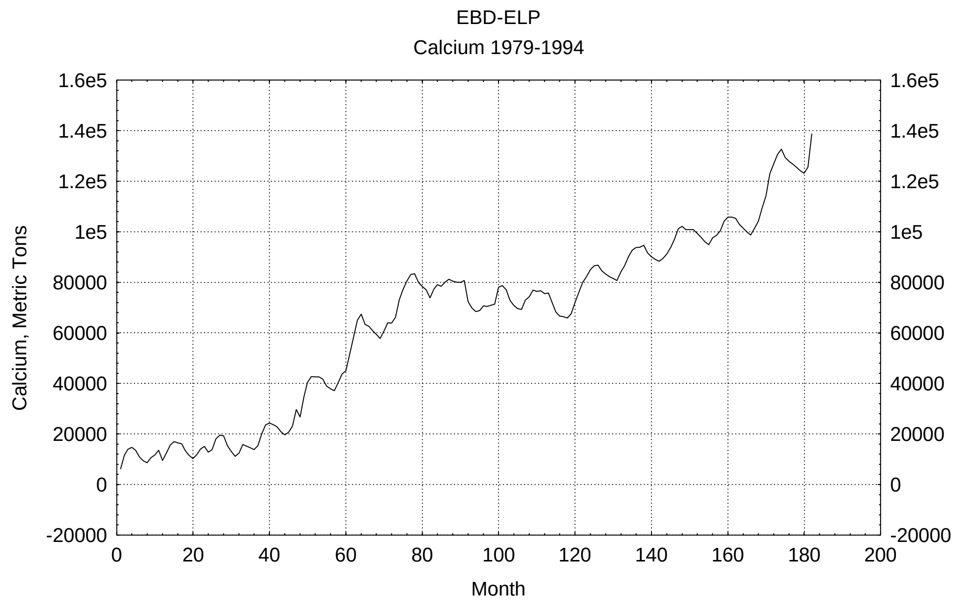
Parameter	p(1)	Qs(1)
p(1)	1	0.1489
Qs(1)	0.1489	1

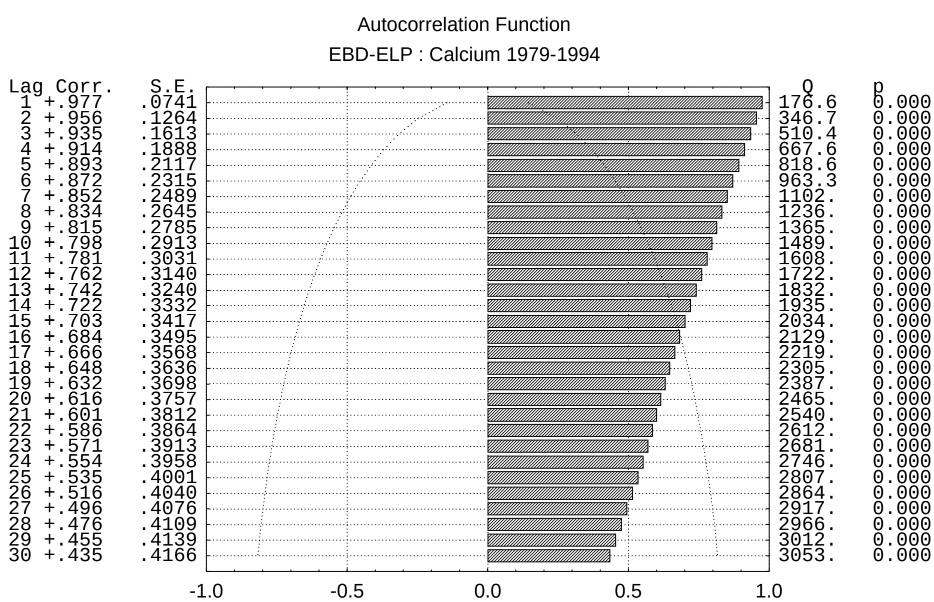
Parameter covariances (Calcium, EBD-ELP, 1934-1963)

Parameter	p(1)	Qs(1)
p(1)	0.0022	0.0003
Qs(1)	0.0003	0.0024

Descriptive statistics (Calcium, EBD-ELP, 1934-1963)

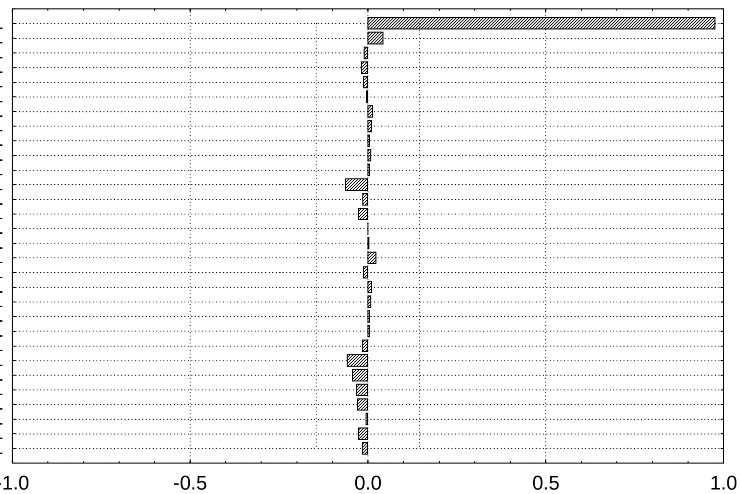
Calcium Metric Tons	Mean	Std.Dev.	Confid. -95%	Confid. 95%	Minimum	Maximum	N
EBD-ELP	77981	58338	71934	84028	-1649	205125	360
D(1),D(12)	-25	2265	-264	214	-8282	9592	347
Model:(1,1,0)(0,1,1)							
Residuals	-20	1731	-203	163	-6580	8079	347


EBD-ELP
Calcium 1979-1994
Calcium, Metric Tons
Month
1.6e5
1.4e5
1.2e5
1e5
80000
60000
40000
20000
0
-20000
0
20
40
60
80
100
120
140
160
180
200

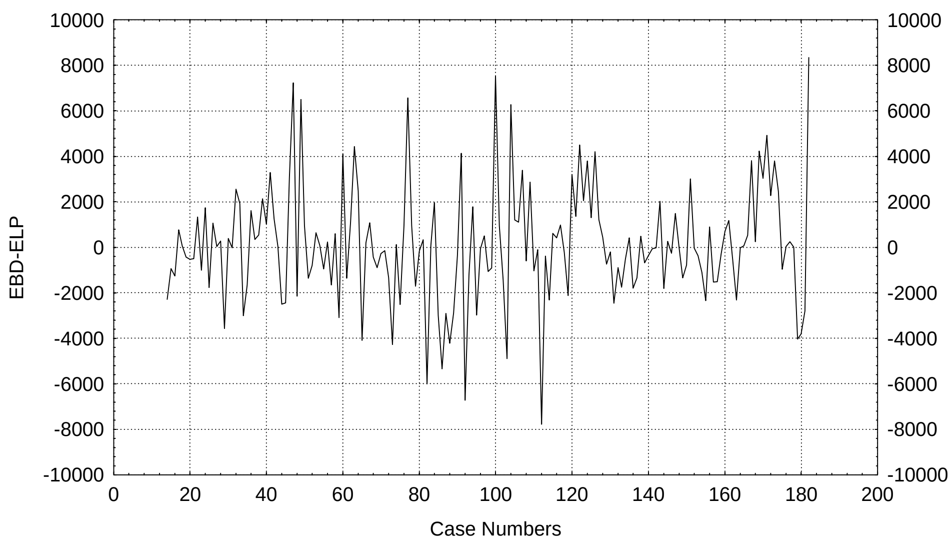

Autocorrelation Function
EBD-ELP : Calcium 1979-1994
Lag Corr. S.E. Q p
1 +.977 .0741 176.6 0.000
2 +.956 .1264 346.7 0.000
3 +.935 .1613 510.4 0.000
4 +.914 .1888 667.6 0.000
5 +.893 .2117 818.6 0.000
6 +.872 .2315 963.3 0.000
7 +.852 .2489 1102. 0.000
8 +.834 .2645 1236. 0.000
9 +.815 .2785 1365. 0.000
10 +.798 .2913 1489. 0.000
11 +.781 .3031 1608. 0.000
12 +.762 .3140 1722. 0.000
13 +.742 .3240 1832. 0.000
14 +.722 .3332 1935. 0.000
15 +.703 .3417 2034. 0.000
16 +.684 .3495 2129. 0.000
17 +.666 .3568 2219. 0.000
18 +.648 .3636 2305. 0.000
19 +.632 .3698 2387. 0.000
20 +.616 .3757 2465. 0.000
21 +.601 .3812 2540. 0.000
22 +.586 .3864 2612. 0.000
23 +.571 .3913 2681. 0.000
24 +.554 .3958 2746. 0.000
25 +.535 .4001 2807. 0.000
26 +.516 .4040 2864. 0.000
27 +.496 .4076 2917. 0.000
28 +.476 .4109 2966. 0.000
29 +.455 .4139 3012. 0.000
30 +.435 .4166 3053. 0.000
-1.0
-0.5
0.0
0.5
1.0

Partial Autocorrelation Function
EBD-ELP : Calcium 1979-1994
(Standard errors assume AR order of k-1)

Lag	Corr.	S.E.
1	+.977	.0741
2	+.043	.0741
3	-.011	.0741
4	-.019	.0741
5	-.013	.0741
6	-.004	.0741
7	+.013	.0741
8	+.011	.0741
9	+.004	.0741
10	+.009	.0741
11	+.006	.0741
12	-.064	.0741
13	-.014	.0741
14	-.026	.0741
15	+.000	.0741
16	+.003	.0741
17	+.023	.0741
18	-.012	.0741
19	+.011	.0741
20	+.009	.0741
21	+.004	.0741
22	+.005	.0741
23	-.016	.0741
24	-.058	.0741
25	-.044	.0741
26	-.031	.0741
27	-.029	.0741
28	-.005	.0741
29	-.026	.0741
30	-.016	.0741



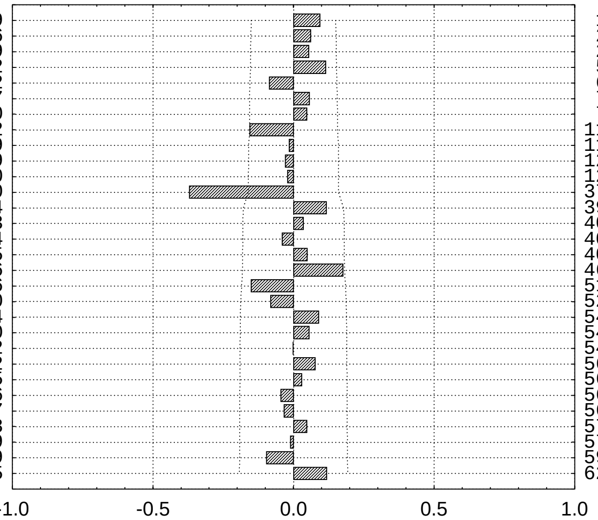
Plot of variable: EBD-ELP
Calcium 1979-1994; D(1),D(12);



Autocorrelation Function

EBD-ELP : Calcium 1979-1994; D(1),D(12);

Lag	Corr.	S.E.	Q	p
1	+.096	.0769	1.58	.2093
2	+.063	.0776	2.27	.3219
3	+.055	.0779	2.80	.4236
4	+.116	.0782	5.15	.2721
5	-.086	.0792	6.47	.2635
6	+.059	.0797	7.08	.3138
7	+.049	.0800	7.51	.3779
8	-.156	.0802	11.86	.1578
9	-.015	.0819	11.90	.2193
10	-.028	.0819	12.04	.2822
11	-.020	.0820	12.12	.3550
12	-.370	.0820	37.33	.0002
13	+.118	.0914	39.92	.0001
14	+.037	.0923	40.17	.0002
15	-.040	.0924	40.47	.0004
16	+.050	.0925	40.94	.0006
17	+.177	.0926	46.91	.0001
18	-.151	.0946	51.28	.0000
19	-.082	.0960	52.58	.0001
20	+.091	.0964	54.19	.0001
21	+.057	.0970	54.83	.0001
22	-.001	.0972	54.83	.0001
23	+.078	.0972	56.04	.0001
24	+.030	.0975	56.22	.0002
25	-.045	.0976	56.62	.0003
26	-.032	.0977	56.83	.0004
27	+.049	.0978	57.32	.0006
28	-.010	.0979	57.34	.0009
29	-.097	.0979	59.28	.0008
30	+.120	.0985	62.28	.0005

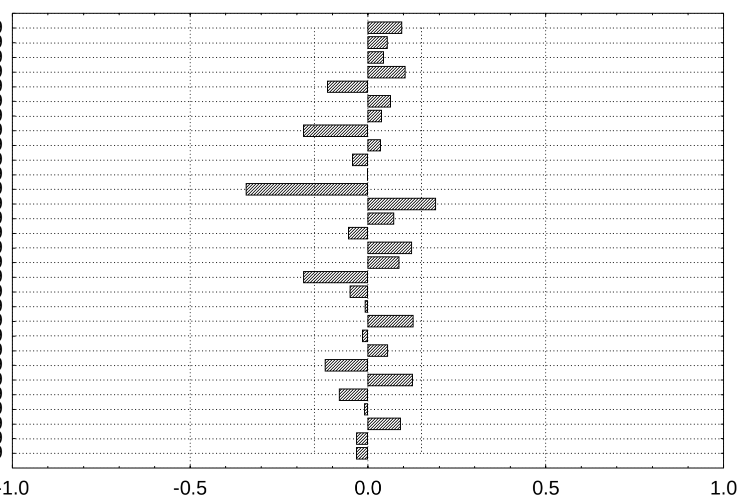


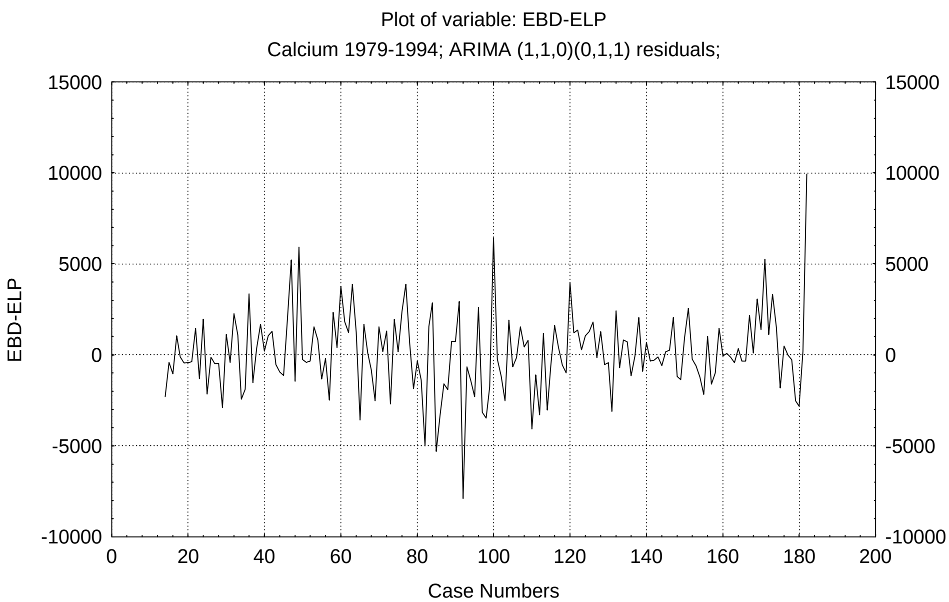
Partial Autocorrelation Function

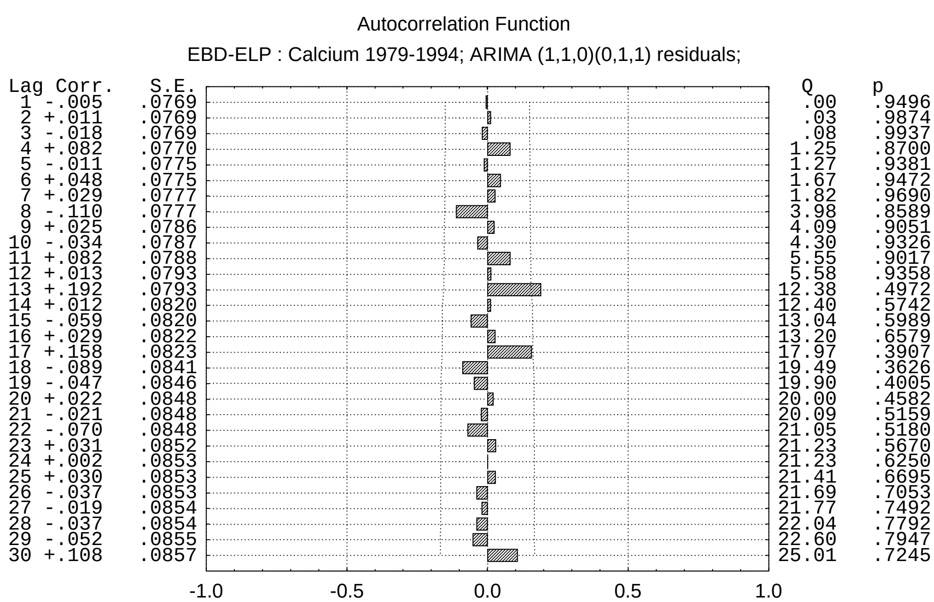
EBD-ELP : Calcium 1979-1994; D(1),D(12);

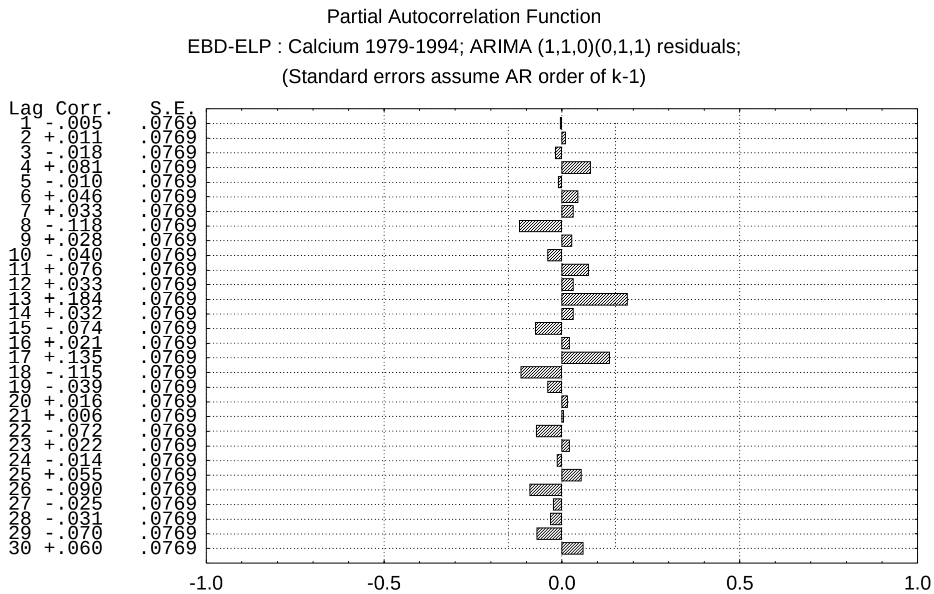
(Standard errors assume AR order of k-1)

Lag	Corr.	S.E.
1	+.096	.0769
2	+.055	.0769
3	+.045	.0769
4	+.105	.0769
5	-.114	.0769
6	+.065	.0769
7	+.039	.0769
8	-.182	.0769
9	+.036	.0769
10	-.043	.0769
11	-.002	.0769
12	-.343	.0769
13	+.191	.0769
14	+.074	.0769
15	-.055	.0769
16	+.124	.0769
17	+.088	.0769
18	-.180	.0769
19	-.051	.0769
20	-.008	.0769
21	+.128	.0769
22	-.016	.0769
23	+.056	.0769
24	-.120	.0769
25	+.126	.0769
26	-.081	.0769
27	-.009	.0769
28	+.091	.0769
29	-.031	.0769
30	-.032	.0769




Plot of variable: EBD-ELP
Calcium 1979-1994; ARIMA (1,1,0)(0,1,1) residuals;
EBD-ELP
Case Numbers
15000
10000
5000
0
-5000
-10000
0
20
40
60
80
100
120
140
160
180
200


Autocorrelation Function
EBD-ELP : Calcium 1979-1994; ARIMA (1,1,0)(0,1,1) residuals;
Lag Corr. S.E. Q p
1 -.005 .0769 .00 .9496
2 +.011 .0769 .03 .9874
3 -.018 .0769 .08 .9937
4 +.082 .0770 1.25 .8700
5 -.011 .0775 1.27 .9381
6 +.048 .0775 1.67 .9472
7 +.029 .0777 1.82 .9690
8 -.110 .0777 3.98 .8589
9 +.025 .0786 4.09 .9051
10 -.034 .0787 4.30 .9326
11 +.082 .0788 5.55 .9017
12 +.013 .0793 5.58 .9358
13 +.192 .0793 12.38 .4972
14 +.012 .0820 12.40 .5742
15 -.059 .0820 13.04 .5989
16 +.029 .0822 13.20 .6579
17 +.158 .0823 17.97 .3907
18 -.089 .0841 19.49 .3626
19 -.047 .0846 19.90 .4005
20 +.022 .0848 20.00 .4582
21 -.021 .0848 20.09 .5159
22 -.070 .0848 21.05 .5180
23 +.031 .0852 21.23 .5670
24 +.002 .0853 21.23 .6250
25 +.030 .0853 21.41 .6695
26 -.037 .0853 21.69 .7053
27 -.019 .0854 21.77 .7492
28 -.037 .0854 22.04 .7792
29 -.052 .0855 22.60 .7947
30 +.108 .0857 25.01 .7245
-1.0
-0.5
0.0
0.5
1.0



Parameter estimates (Calcium, EBD-ELP, 1979-1994)

Transformations: D(1),D(12) Model:(1,1,0)(0,1,1) Seasonal lag: 12 MS Residual=4809E3						
		Asympt.	Asympt.		Lower	Upper
	Param.	Std.Err.	t(167)	p	95% Conf	95% Conf
p(1)	0.2259	0.0809	2.7915	0.0059	0.0661	0.3857
Qs(1)	0.6932	0.0664	10.4338	0.0000	0.5620	0.8243

Parameter correlations (Calcium, EBD-ELP, 1979-1994)

Parameter	p(1)	Qs(1)
p(1)	1	0.09172
Qs(1)	0.09172	1

Parameter covariances (Calcium, EBD-ELP, 1979-1994)

Parameter	p(1)	Qs(1)
p(1)	0.0066	0.0005
Qs(1)	0.0005	0.0044

Descriptive statistics (Calcium, EBD-ELP, 1979-1994)

Calcium Metric Tons	Mean	Std.Dev.	Confid. -95%	Confid. 95%	Minimum	Maximum	N
EBD-ELP	64873	35292	59711	70035	6193	138745	182
D(1),D(12)	108	2548	-279	495	-7776	8348	169
Model:(1,1,0)(0,1,1)							
Residuals	116	2183	-216	447	-7888	9943	169

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