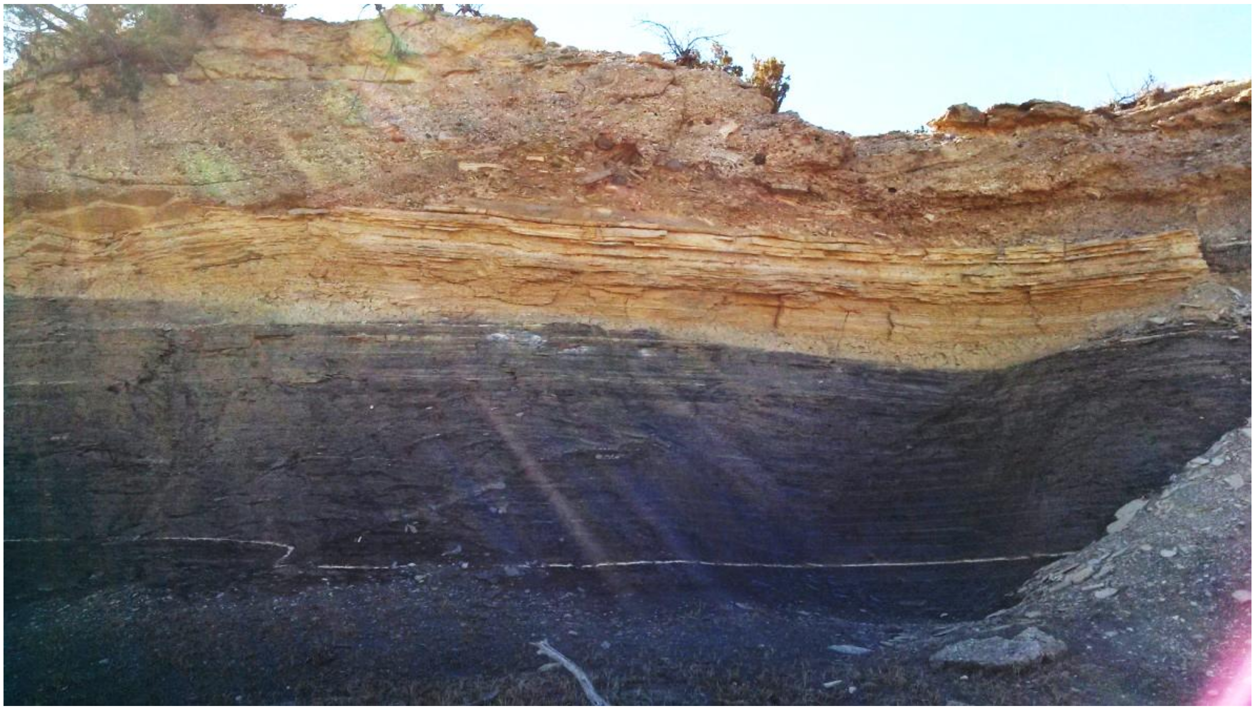
Union County Hydrogeology Project

Annual Progress Report

2012-2013



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Contents

Introduction

This report is Zeigler Geologic Consulting, LLC's (ZGC) annual progress report for the Union County Hydrogeology Project, sponsored by the Northeastern Soil and Water Conservation District. During the 2012-2013 fiscal year, ZGC measured static water level in 50 wells in August and January, revised the 1:50,000 geologic map west of the town of Clayton, obtained 20 water chemistry samples and four radiocarbon dating samples, examined well cuttings from five petroleum wells and installed eight data recorders. Here we describe the progress in each of these tasks.

Static Water Level Measurements

Beginning in 2007, depth to water has been measured in fifty wells spread across the county in January (minimum pumping) and August (maximum pumping). A 300 ft steel tape is used for most of the wells and a 500 ft steel tape for wells deeper than 300 ft. For open casing wells, we use a well level sounder (maximum length of 300 ft). The measuring point, or height of the entrance to the well above land surface, is subtracted from the total depth measurement such that the final static water level for all wells is calculated relative to the land surface. Measurements are repeated until two values that are within 0.5 ft of one another are obtained. In August, during heavy pumping near or at many of these wells, a minimum of 15 minutes was allowed to pass after turning off the pump before measurements were begun in order to allow the local water table to stabilize. Four wells have been removed from the study for various reasons (going dry, casing disintegrating, etc.): 20N 35E 01.211, 22N 36E 04.121, 24N, 36E 12.111, 25N, 31E, 20.222. One well was added to the study to replace 24N 36E 12.111: 31N 37E 18.424.

Of the fifty wells that have been tracked, 24 show an overall increase in the water level and 26 show a decline (numbers include wells dropped from the study in 2012 and 2013). Individual hydrographs for each well are found in Appendix I. Water level trends were determined using only the January measurements in order to avoid potential issues with measurements on wells that had perhaps not fully recovered after having pumps turned off. Average increase is 1.1 ft and the average decline is 1.5 ft, each over six years. Geographically, wells that show a decline are located primarily around the Sedan and Seneca Valley areas, with a smaller area of decline east of Gladstone (Figure 1, Table 1, Appendix II). Regional groundwater flow in the Union County area is generally from northwest to southeast (Baldwin and Bushman, 1957)

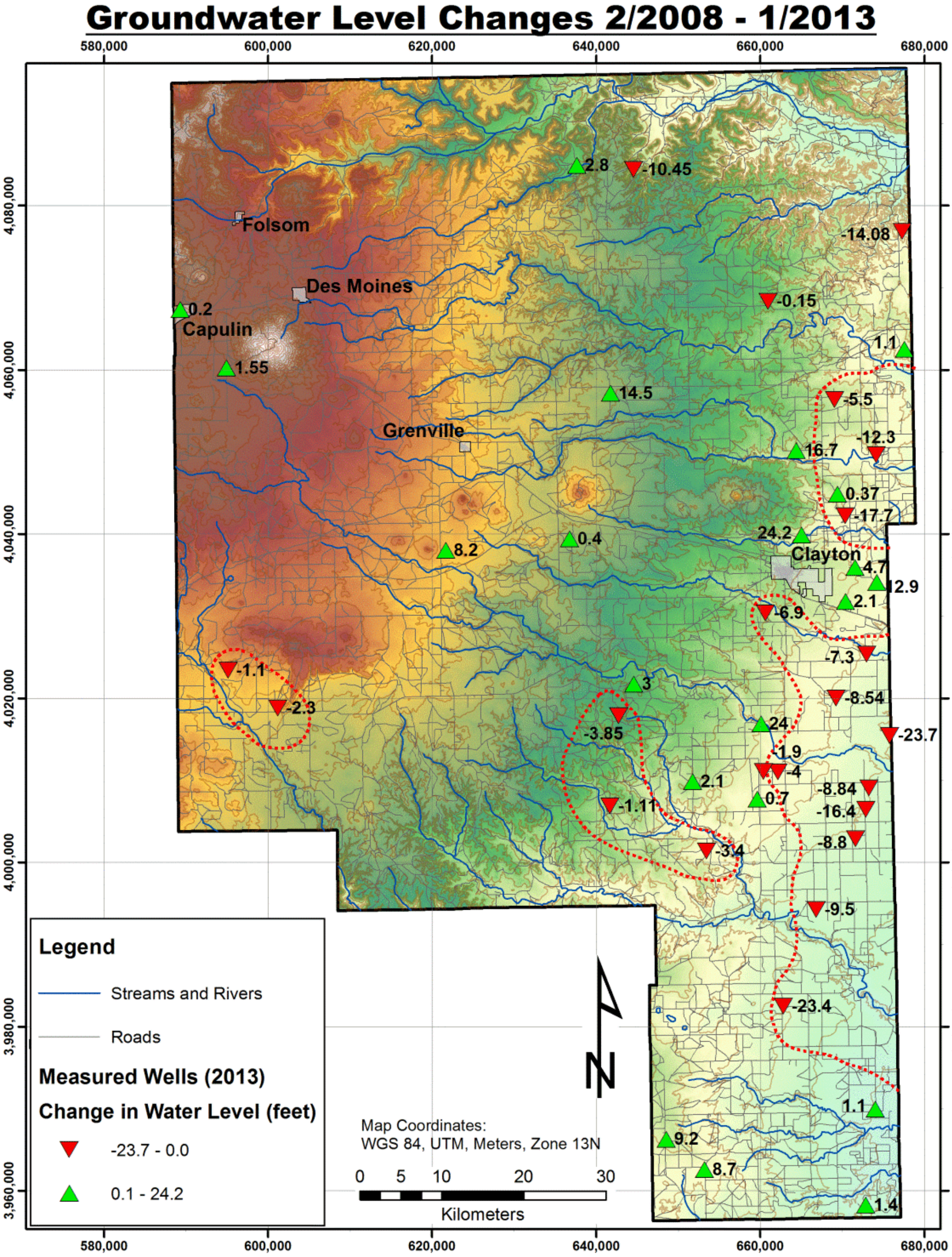

Figure 1. Changes in static water level from January 2008 to January 2013.

Water Chemistry

Approximately two liters of water were collected from each of twenty wells scattered across the county for basic water chemistry analyses of major cations and anions. Wells were allowed to flow for 10 minutes prior to collecting a sample if the well was off upon arrival. For stock tanks where the windmill was actively pumping on arrival, a sample was collected within a few minutes. The analytical work was conducted by Hall Environmental of Albuquerque and analyses included the cations calcium (Ca), sodium (Na), magnesium (Mg) and potassium (K), and the anions carbonate (CO_3), bicarbonate (HCO_3), sulfate (SO_4) and chloride (Cl) (Figure 2).

Each of the ions analyzed for can provide information about groundwater-rock unit interactions. A brief overview of each ion follows here (based on Hem, 1985) and we recommend Hem's (1985) *Study and Interpretation of the Chemical Characteristics of Natural Waters* for an in-depth review of groundwater chemistry.

Calcium is the most abundant of the alkaline-earth metals and is an important part of many igneous, metamorphic and sedimentary rocks. In igneous rocks, the minerals pyroxene, amphibole and the feldspar family contain calcium, but in general, groundwater that interacts with igneous rocks has relatively low concentrations of calcium due to the slow decomposition rates of most of these minerals. In sedimentary rocks, calcium occurs most commonly in carbonate rocks, such as limestone and dolomite, and in the sulfate evaporites gypsum and anhydrite. In sandstone, calcium is generally present as a cementing agent and in soils it is present as an adsorbed ion on negatively charged surfaces.

Magnesium is also an alkaline-earth metal that is important in mafic igneous rocks, occurring in minerals such as pyroxene, amphibole and olivine. In sedimentary rocks, magnesium occurs as a carbonate (magnesite) or as a mixture with calcium (e.g., limestone and dolomite). Magnesium carbonates are more soluble than calcium carbonates. Hem (1985) notes that magnesium concentration tends to increase along groundwater flow paths. Sodium is the most abundant of the alkali metals and is an important constituent in igneous and sedimentary rocks in the feldspar mineral family. Feldspars that include a mixture of sodium and calcium tend to be more susceptible to chemical weathering. In sedimentary rocks, evaporites (e.g., rock salt) are important sources of sodium, as well as sodium occurring as part of unaltered minerals, an impurity in a cement or as a residue left over by saline waters that interacted with sediments or sedimentary rocks after depositions. In interbedded shales and sandstones, sodium is often held in the less permeable shales and with long-term groundwater withdrawal and declining water tables, this sodium can be reintroduced into the groundwater from the shales.

Potassium goes into solution less readily than does sodium and tends to be incorporated back into solid weathering products during chemical weathering. It is an important ion in many igneous rock minerals, including the feldspar family and micas. In sedimentary rocks, potassium is a constituent of unaltered feldspar grains, micas, clays minerals and some evaporites. Because it is less soluble than sodium, potassium concentrations tend to be relatively low. Carbonate and bicarbonate are produced as part of the interactions of water and carbonates (e.g., limestone and dolomite). Bicarbonate concentrations are higher in more acidic waters and carbonate concentrations are higher in more basic waters.

Sulfate occurs as a result of the chemical weathering of sulfide minerals with aerated waters. In this reaction, sulfur is oxidized to form sulfate ions. In sedimentary rocks, pyrite is a common mineral host for sulfur that occurs in association with biogenic deposits, such as coal. The most important contributors for sulfate are the evaporite rocks gypsum and anhydrite.

Chloride is the most abundant halogen but conversely has one of the lowest concentrations in rocks. It is generally most common in sodalite (a feldspathoid) and apatite (a calcium phosphate), as well as occurring as an impurity in other minerals. In sedimentary rocks, chloride occurs as inclusions in brine deposits, in cements or as incompletely leached deposits that formed in ocean or closed basins. Chloride tends to be moved through the hydrologic cycle by physical processes, as opposed to chemical processes (Hem, 1985). Generally, where sodium is the dominant cation present, chloride will be the dominant anion (primarily due to the relationship of sodium and chloride ionically bound together as halite, or rock salt).

The chemistry of the water in each well reflects primarily the bedrock unit(s) that the well is drawing water from (Figure 2). These wells appear to be screened along most of their length, such that wells that penetrate more than one geologic unit will have mixed waters. In general, water from wells that are completed in the Dakota Group contain higher abundances of carbonate, bicarbonate, calcium (Ca) and magnesium (Mg). Water from wells completed in the Jurassic Morrison Formation contain significant quantities of sodium (Na) and potassium (K), and water from wells that penetrate units with black shale (Dakota Group, Graneros Shale) contain sulfate.

These differences in chemistry reflect the differences in mineralogy among these bedrock units. Dakota Group sandstones are cemented with calcite, which can dissolve to provide CO_3, HCO_3, Ca and Mg. Black shales, which are commonly interbedded with sandstone in the Dakota Group, and constitute the primary lithology of the Graneros Shale, contain gypsum, a calcium sulfate, which provides sulfate (SO_4). The Morrison Formation is rich in feldspars, which can contain sodium and potassium, providing these two cations. Wells that include a mixture of waters from the Dakota Group and the Morrison will thus include some proportion of all the ions expected for those waters.

In a few cases, water chemistry results revealed that wells were completed in different units than expected (Figure 2). For example, well 23N 33E 28.432 at old Clapham was expected to yield a Dakota Group chemical signature, but contained high levels of sodium and potassium, indicating that this well is probably partially completed in the Morrison Formation and includes both Morrison and Dakota waters. This unexpected result reflects the complexity of the subsurface, as discussed below.

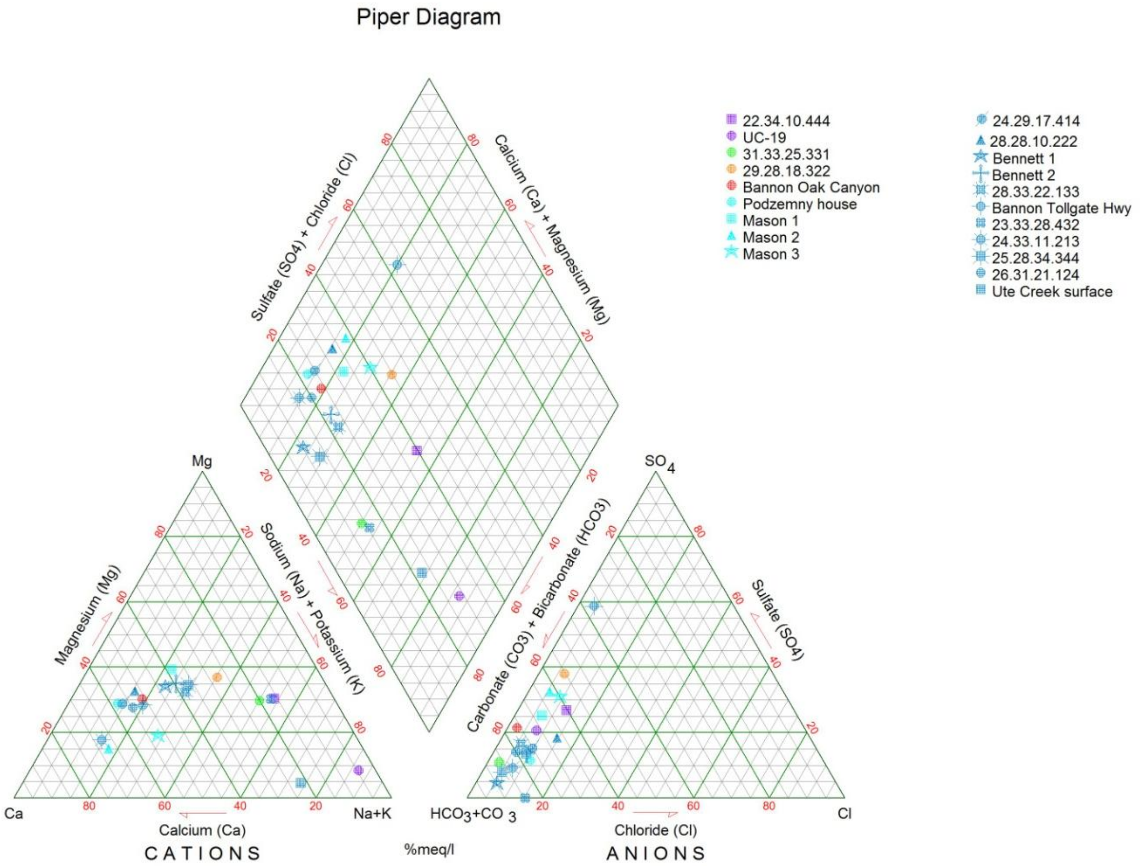

Figure 2. Piper diagram for water chemistry samples collected Janurary 2013 from Union County.

Carbon-14 Dates

We collected one liter of water from each of four wells in a northwest-southeast transect across the county (Figure 3). Nitric acid (HNO_3) was added to each sample as a preservative and the samples were analyzed by Beta Analytic, Inc. in Miami, Florida.

Groundwater age is related to the rate at which water migrates through the subsurface. It is important to remember that water molecules may enter and leave the system via cross-formational flow and that any given mass of groundwater will exchange water molecules with masses of water on all sides of it (Bethke and Johnson, 2008). Hence, a mass of water that entered the groundwater and had a single age associated with it will end up with many of those particles dispersed, rather than traveling entirely as a discrete package. A groundwater sample, therefore, is an average of the ages of all of the molecules of water contained in that sample (Bethke and Johnson, 2008). The distribution of these ages for each sample may include much older molecules and much younger molecules, and may be heavily skewed in one direction or the other. Dating methods, including Carbon-14 (^{14}C), generally include the assumption that the groundwater mass is acting as a closed system after it infiltrates below the water table. ^{14}C is used for materials that are assumed to be less than 50,000 years old and has a half-life of 5,730 years. It is produced by cosmic rays in the atmosphere and the ^{14}C is then dissolved as CO_2 in rainfall and as the moisture occurring in roots in the vadose zone. ^{14}C is then introduced into the groundwater system by infiltration of surface waters or water migrating downward from the root zone. One complication for the ^{14}C method is that the oxidation of ancient organic matter or the dissolution of carbonates (e.g., limestone) will add ^{14}C-depleted carbon (also called “dead” carbon) into the groundwater (Bethke and Johnson, 2008). This process will create an erroneously old age and so ages of water extracted from systems that are suspected of including carbonate interactions should be corrected for this depleted carbon addition.

For this study, geochemical interactions with the host rocks in the Dakota Group and Morrison Formation are unlikely to contribute significant amounts of “dead” carbon due to a lack of significant quantities of carbonate rocks. The ^{14}C sampling transect was chosen to intersect with a north-south transect of radiocarbon samples obtained in 2011 by the New Mexico Bureau of Geology & Mineral Resources (NMBGMR) that showed a possible younging trend to the west. The dates obtained by ZGC do show a very young date, 190 radiocarbon years before present (RCYBP, where present is set at 1950), at the westernmost well (28n 28E 10.222), but there is no obvious trend of older waters to the west (Figure 3). For example, the sample obtained from a well near Grenville (26N 31E 21.124), east of the westernmost well, yielded a date of 5110 RCYBP. The very young age at the westernmost well suggests some degree of interaction with younger waters infiltrating from the surface. Future work will include a tritium age analysis for at least the youngest of the waters sampled.

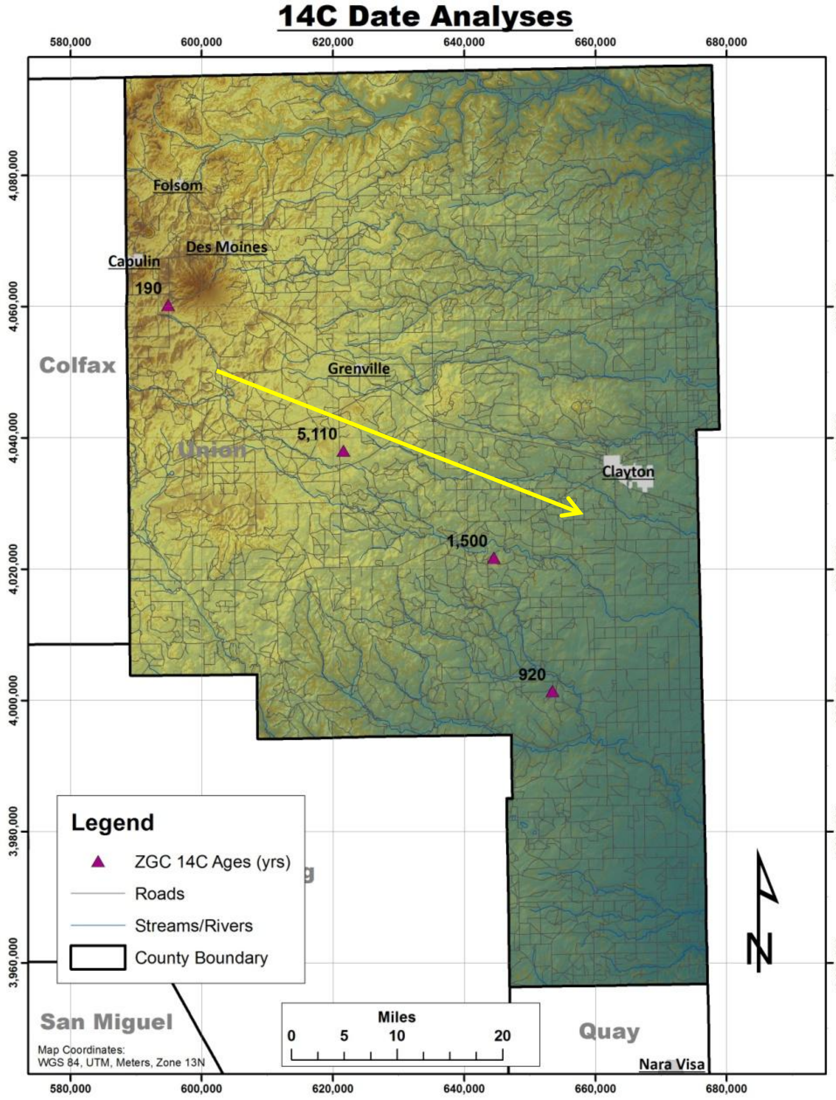

Figure 3. ^{14}C age determinations for four wells sampled in January of 2013. Yellow arrow indicates general direction of regional groundwater flow.

The apparent lack of a trend of younger waters to the east obtained across Union County suggest that the aquifer units (Dakota Group, Morrison Formation) are more internally partitioned than might otherwise be expected. In addition, complex folding of the rocks in the subsurface brings older rocks (and thus, older waters) closer to the surface.

Geologic Mapping

We have revised the geologic map of the 1:50,000 quadrangle immediately west of town of Clayton. This quadrangle includes exposures along Perico and Carrizo Creeks, as well as large tracts of Quaternary eolian sheet deposits and young basalt flows from the Raton-Capulin-Clayton volcanic field. Perico Creek includes several interesting exposures of the Miocene-Pliocene Ogallala Formation, the Cretaceous Graneros Shale and Dakota Group. The Graneros Shale has thicker outcrops here than to the east and the Ogallala is thinner, reflecting both the beveling of the Graneros Shale during pre-Ogallala erosion and the onlapping of the Ogallala Formation onto the Rocky Mountain uplift to the west. Geologic mapping of the county is ongoing. Further revisions will be presented in subsequent reports.

Petroleum Well Cuttings and Subsurface Analysis

Ten petroleum wells, along with several water wells, have provided a window into the subsurface of eastern Union County. By examining cuttings and well logs associated with these wells, we are able to construct a picture of where the various bedrock units are in the subsurface. The preliminary north-south transect produced in 2011 and 2012 and reviews of Baldwin and Muehlberger (1959) demonstrated that the subsurface geology is more complex than might otherwise be assumed. Baldwin and Muehlberger (1959) documented the presence of the Clapham anticline in southern Union County, which is reflected by exposures of the Jurassic Morrison Formation in Tramperos Creek and tributary drainages between Nara Visa Highway and the abandonded village of Clapham on Thomas Highway. Therefore, in some areas, wells that were previously identified as being completed in the Cretaceous Dakota Group are actually completed in the Morrison Formation. Along with the radiocarbon dates, the subsurface demonstrates the complexity of the aquifer system in Union County and suggests that assumed interactions between different wells geographically close to one another may not actually occur.

Five additional petroleum well cuttings lying along a northwest-southeast transect have been examined to a depth of 700’ in each well and the detailed cutting descriptions are listed in Appendix III. Two of the wells, the Amoco #1 State EW and Amoco #1 State EZ, were missing intervals of cuttings or had potential contamination problems and so are not included in subsurface analyses for this report. The farthest northwest of these five wells, the Texaco “CT” Click NCT-1, includes 20+ ft of basalt overlying approximately 160 ft of Ogallala sands and gravels (Figure 4). Below the Ogallala are sedimentary strata interpreted to be part of the Cretaceous Graneros Shale, based on the presence of limestone-dominated intervals and occasional occurrence of gypsum. The Graneros Shale is interpreted to be about 160 ft thick and overlies Dakota Group shales and sandstones that are approximately 190 ft thick. Below the Dakota Group are siltstones, shales and sandstones of the Glencairn Formation that include crystals of pyrite. To the southwest, the Dillard State #1 includes about 245 ft of Morrison Formation, underlain by 455 ft of Triassic Chinle Group (Figure 4). The southeastern-most well is the Olson #1 Zurick. The upper 230 ft worth of samples are missing, followed by approximately 130 ft of Morrison Formation and a thin interval of sandstone interpreted to be the Exeter (or Entrada) Sandstone. The remainder of the cuttings are interpreted as Chinle Group (Figure 4).

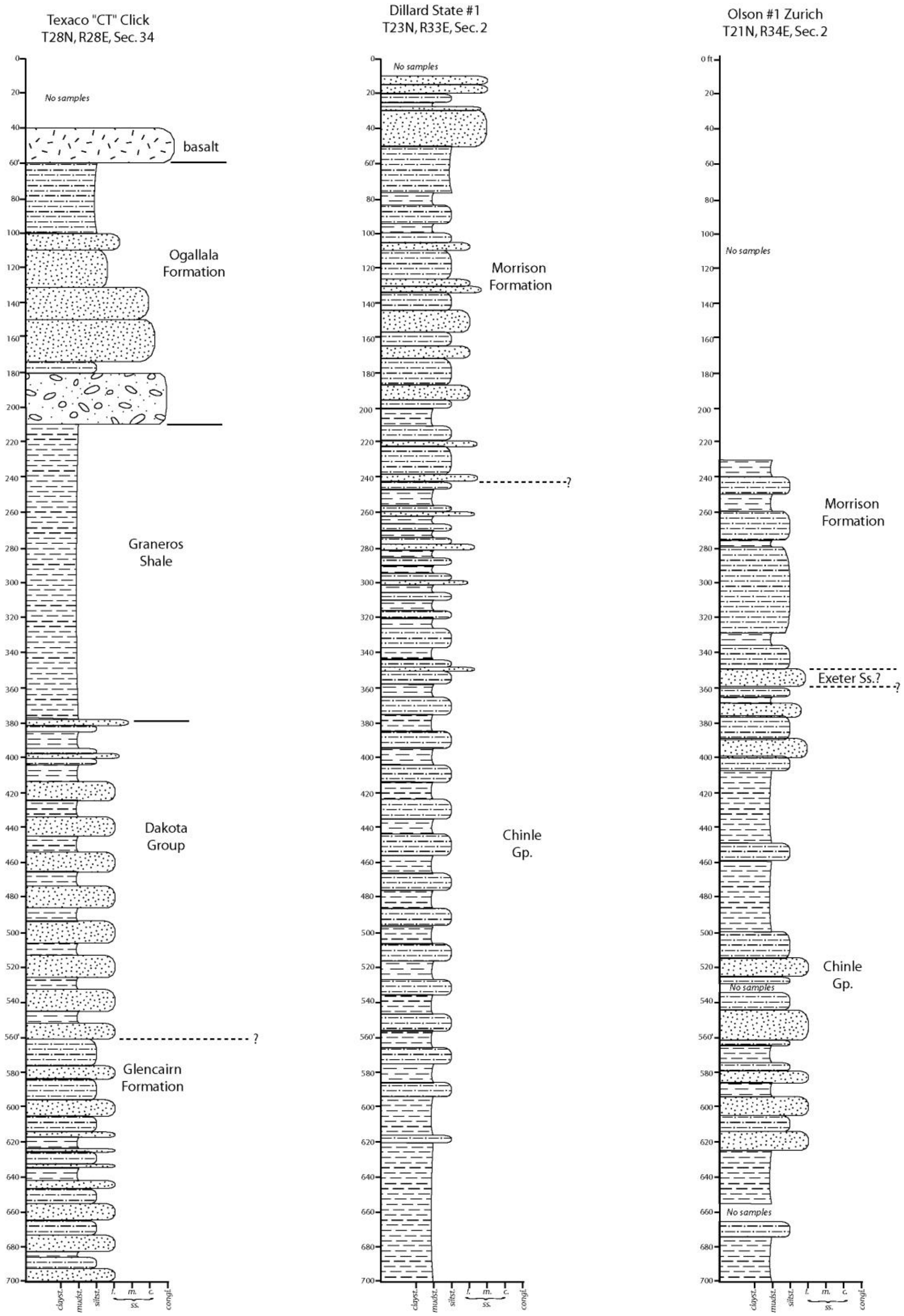

Figure 4. Selected interpretive stratigraphic columns developed from petroleum well cuttings.

Data Recorders

In the spring of 2013, eight data recorders were installed in wells that had been abandoned. The wells were chosen along a northwest-southeast transect that begins at the Texas state line and ends just southwest of Clayton. The data recorders are programmed to record the static water level in each well twice a day (at 6 am and 6 pm). The data recorders are removed from the wells every three months so that the data can be downloaded and then are returned to the wells. One data recorder was lost in the first three months of operation. The remaining seven will be monitored for at least one year. Six of the seven recorder hydrographs appear nearly identical and show primarily a barometric pressure response, with small daily fluctuations (Appendix III). The Cowen North well was set to record every five minutes, thus the hydrograph for this well appears smoother compared to the others. This well shows a decline in water level beginning in mid-May. The R. Seamans well, which is deeper than the other six wells, records the onset of irrigation at a nearby field in early May, but shows barometric pressure fluctuations less clearly.

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Tables

Table 1. Change in static water level measurements (January 2008 to January 2013) for wells measured biannually and the average rate of change of the time period measured for each well.

Well ID	Change in Depth	Years Measured	Rate of Change
18N36E35.111	1.4	6	0.2
18N34E15.422	8.7	6	1.5
19N34E32.133	9.2	6	1.5
19N36E23.244	1.1	6	0.2
20N35E11.333	-23.4	6	-3.9
20N35E01.211	1.61	5	0.3
21N36E35.122	-11.38	5	-2.3
21N35E01.224	-9.5	5	-1.9
22N34E10.444	-3.4	6	-0.6
22N36E04.121	-16.68	5	-3.3
22N36E10.411	-8.8	6	-1.5
23N36E35.111	-16.4	6	-2.7
23N33E28.432	-1.11	6	-0.2
23N35E29.122	0.7	6	0.1
23N36E23.341	-8.84	6	-1.5
23N34E16.442	2.1	6	0.3
23N35E15.211	-4	6	-0.7
23N35E16.121	-1.9	6	0.3*
24N36E36.422	-23.7	6	-4.0
24N35E28.134	24	6	4.0
24N33E22.322	-3.85	6	-0.6
24N29E17.414	-2.3	6	-0.4
24N33E11.213	3	6	0.5
24N36E.12.111	Dropped		
24N36E17.244	-8.54	6	-1.4
25N28E34.344	-1.1	6	-0.2
25N36E.35.311	-7.3	6	-1.2
25N35E30.222	0.6	5	0.1
25N31E20.222	5.36	4	1.3
25N35E16.132	-6.9	6	-1.2
25N36E09.411	2.1	6	0.4
25N36E.02.243	12.9	6	2.2
26N36E.27.343	4.7	6	0.8
26N31E.21.124	8.2	6	1.4

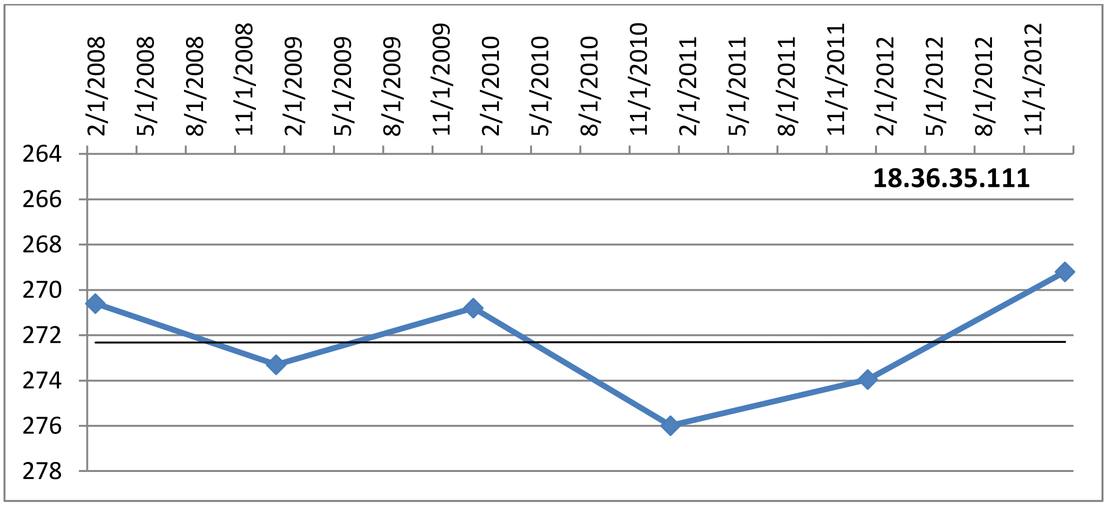
26N32E.13.243	0.4	6	0.1
26N35E.13.143	24.2	6	4.0
26N36E.09.212	-17.7	6	-3.0
27N36E.33.133	0.5	6	-0.1*
27N36E13.311	-12.3	6	-2.1
27N35E.13.111	16.7	6	2.8
27N37E.18.222	-12.2	5	-2.4
28N36E28.131	-5.5	6	-0.9
28N33E.22.133	14.5	6	2.4
28N28E.10.222	1.55	6	0.3
28N37E.05.233	1.1	6	0.2
29N35E.15.313	-0.15	6	0.0
29N28E.18.322	0.2	6	0.0
30N37E20.321	-14.08	6	-2.3
31N33E25.331	-10.45	6	-1.7
31N33E.30.212	2.8	6	0.5
31N37E.18.424	-1.18	4	-0.3

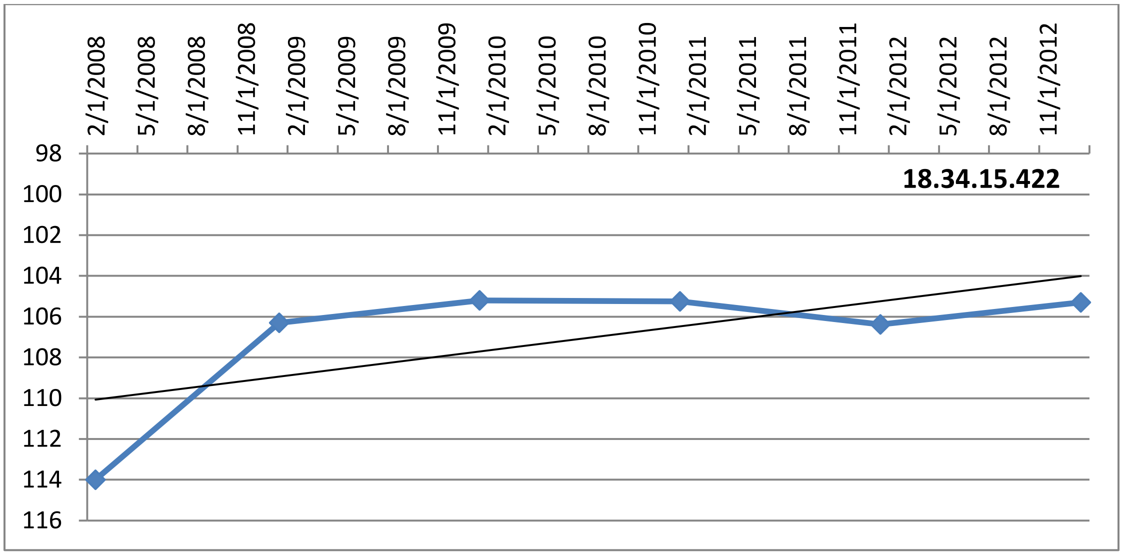
*Overall trend for these wells is different from simple subtraction of the beginning measurement in January 2008 from the January 2013 measurement.

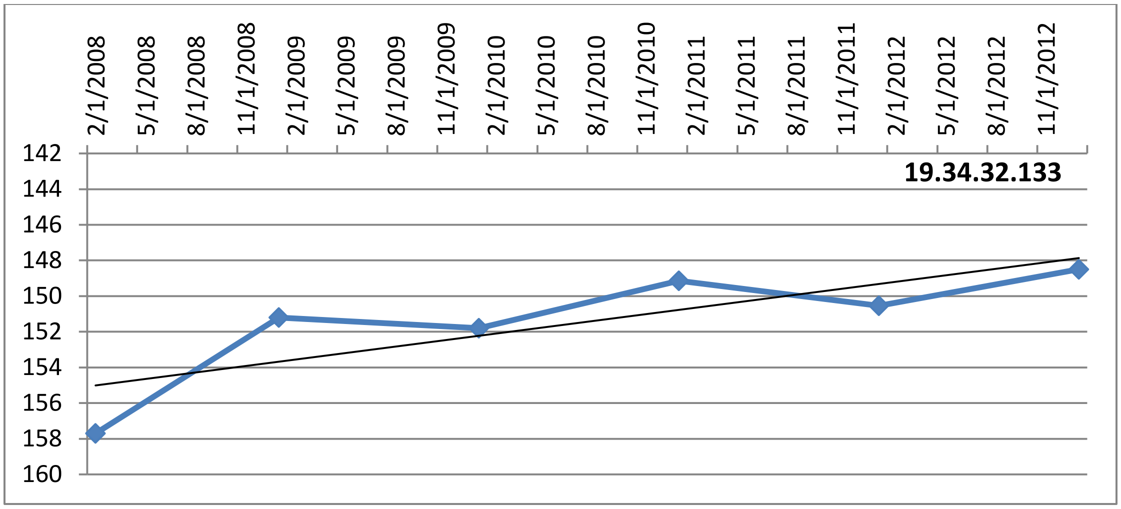
Appendices

Appendix I: January Static Water Level Measurements 2008-2013

Hydrographs for wells that have been measured around Union County from 2008 until present. Wells are listed in order from the far southeast corner of the county up to the Dry Cimarron Valley. Trend line is dark solid line on each graph.



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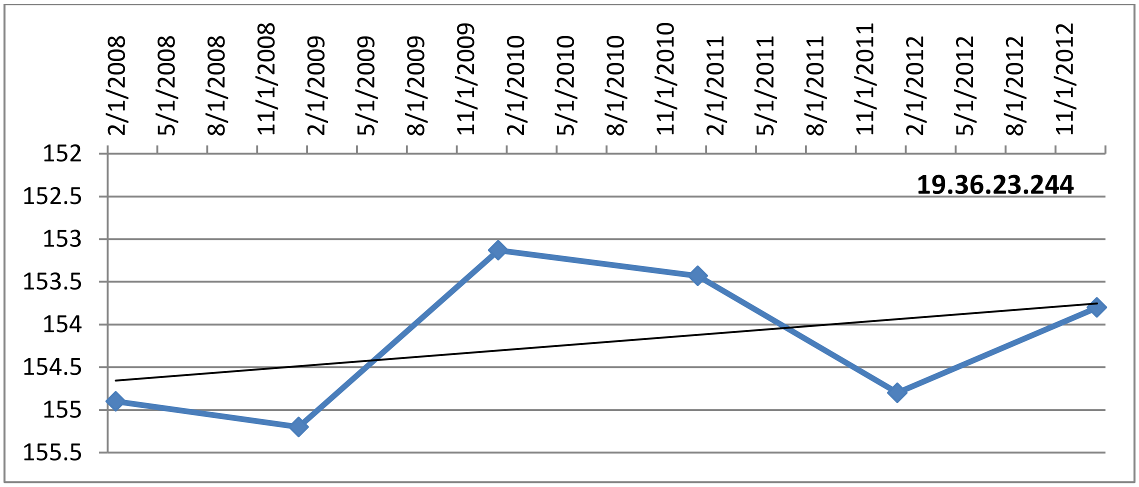
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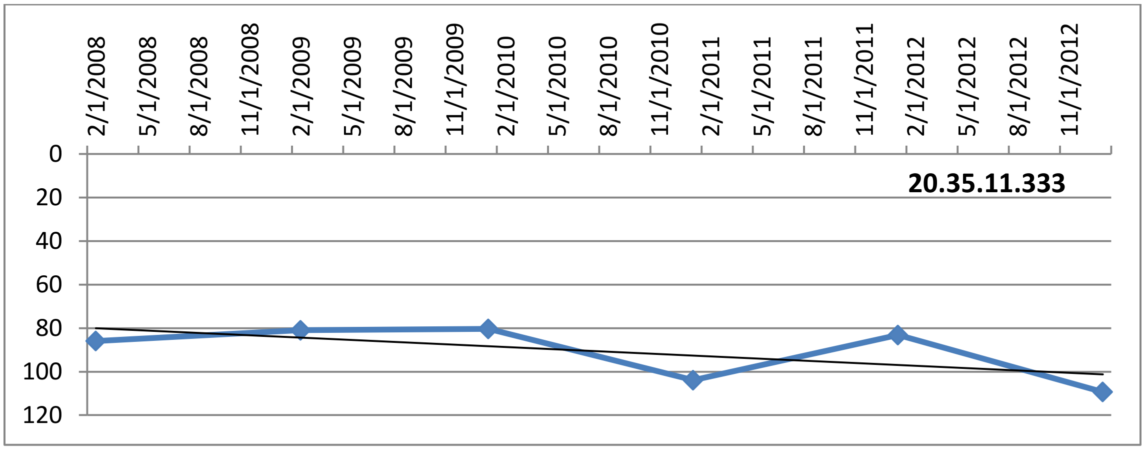
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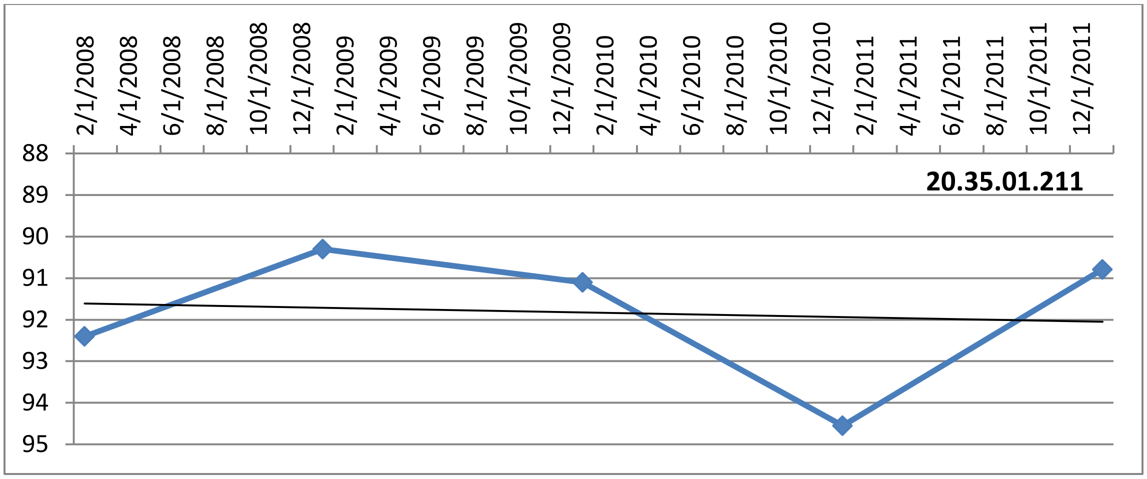
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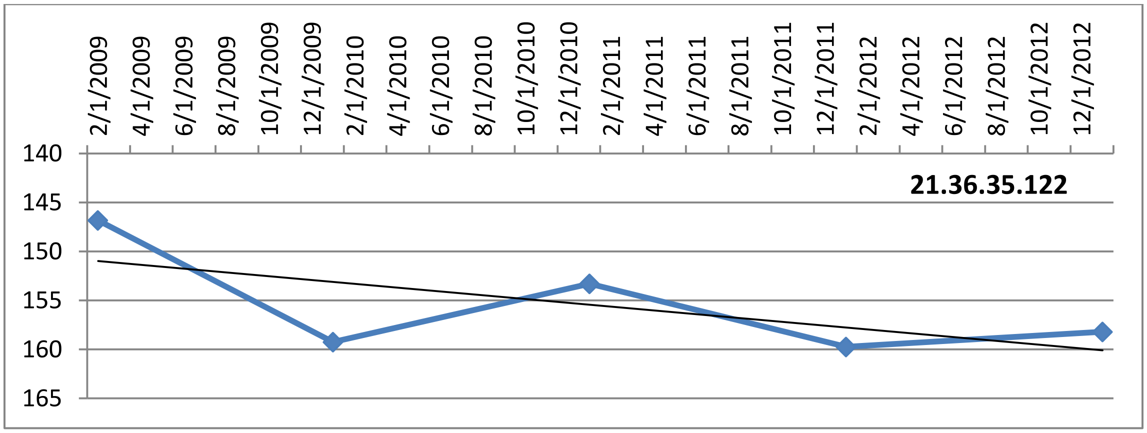
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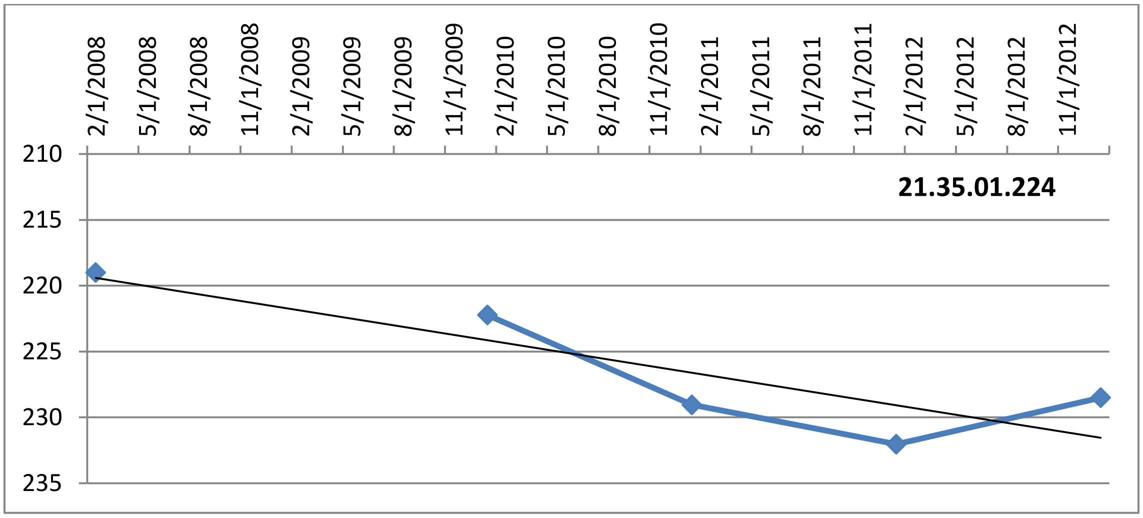
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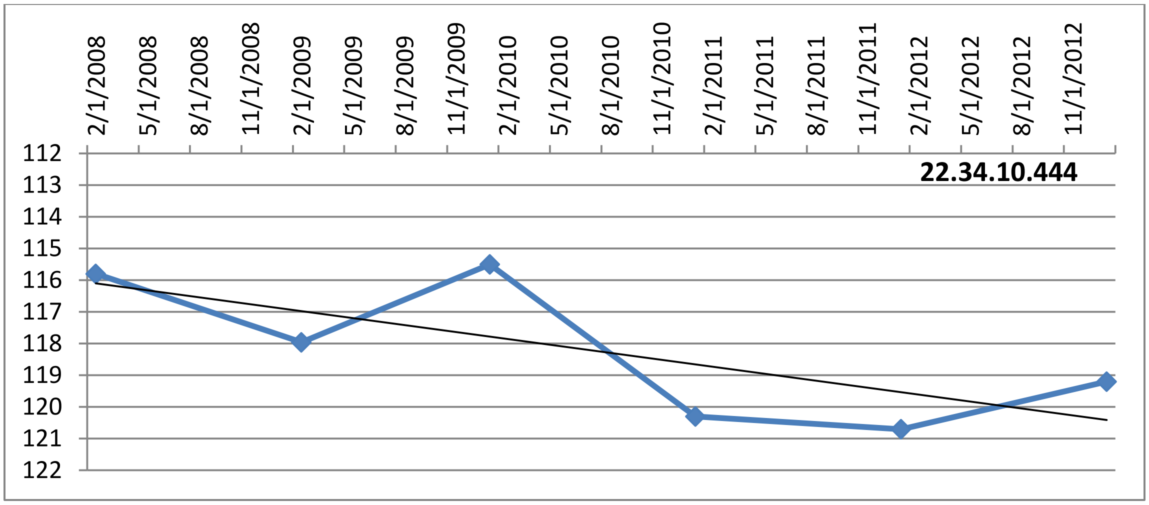
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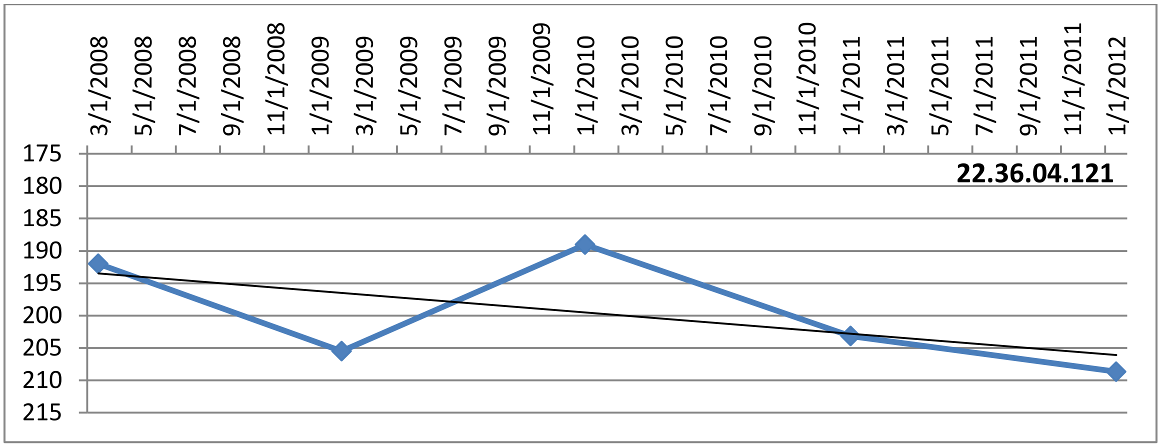
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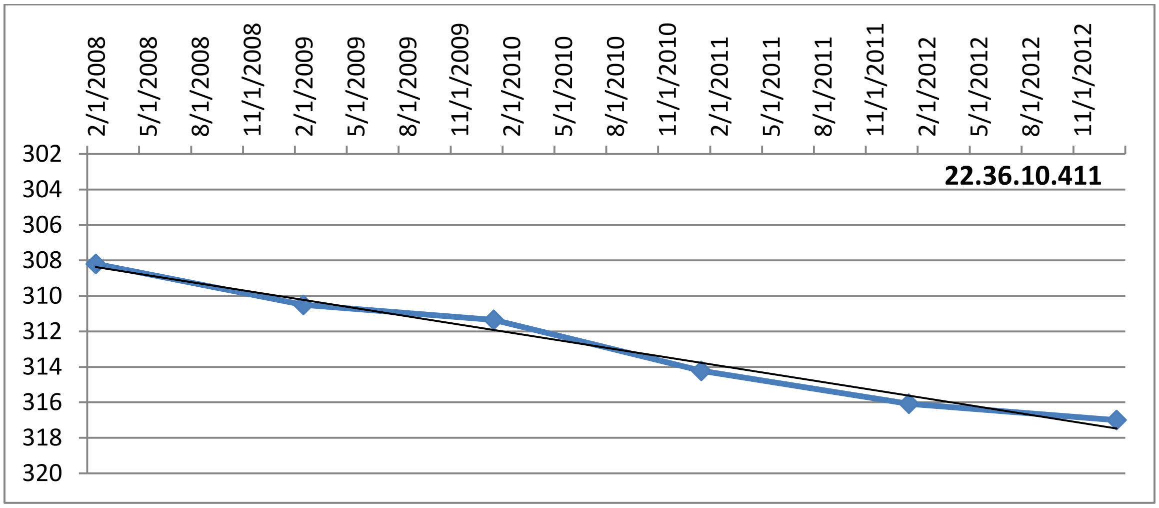
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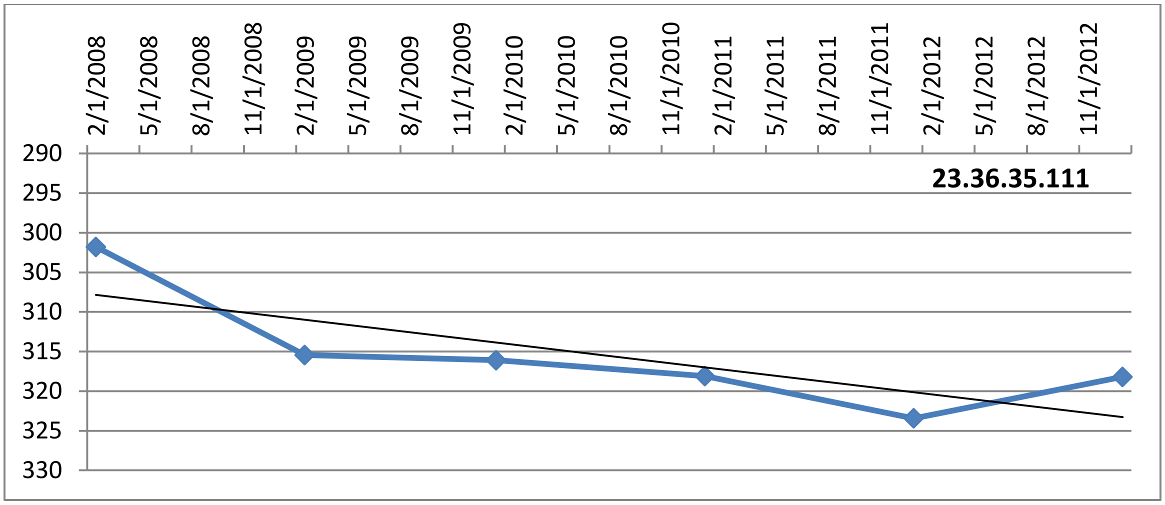
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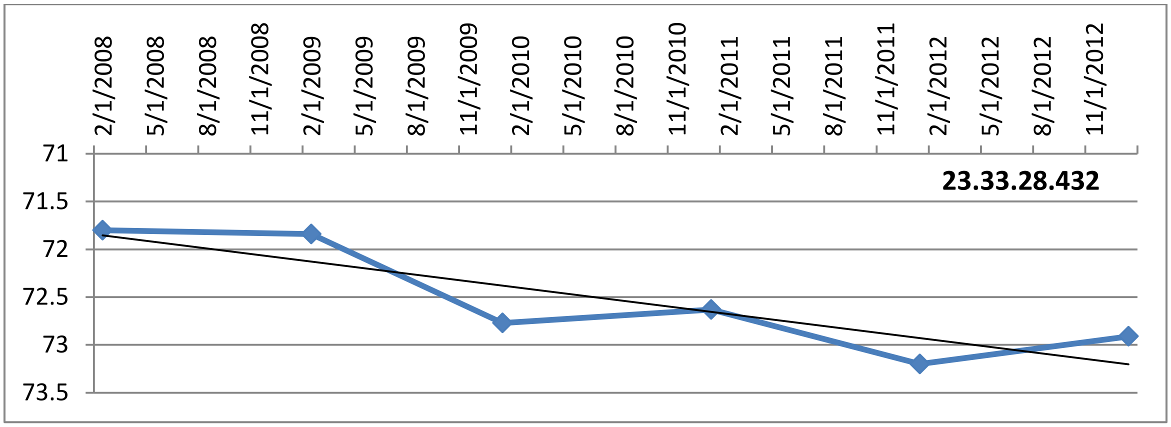
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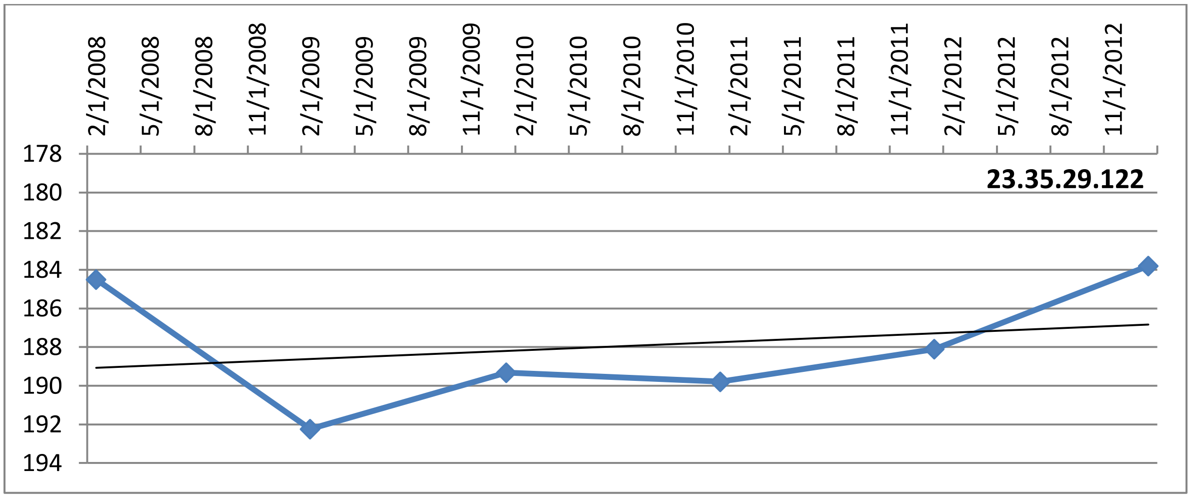
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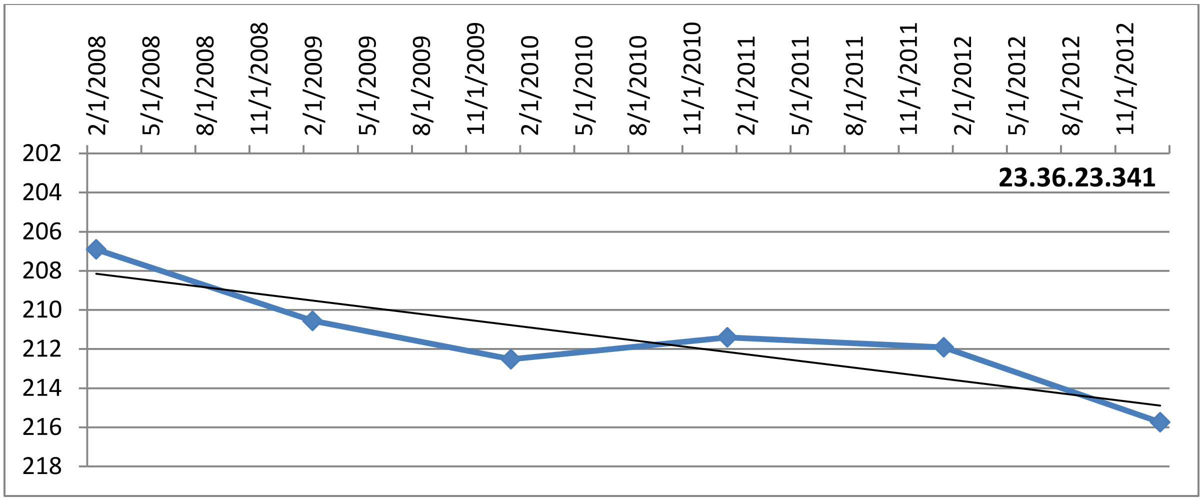
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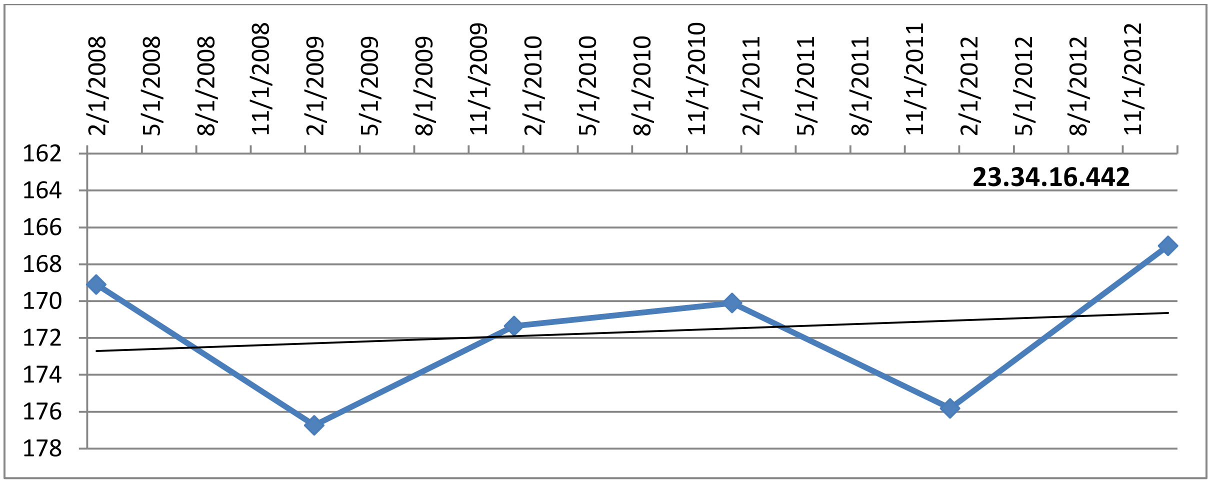
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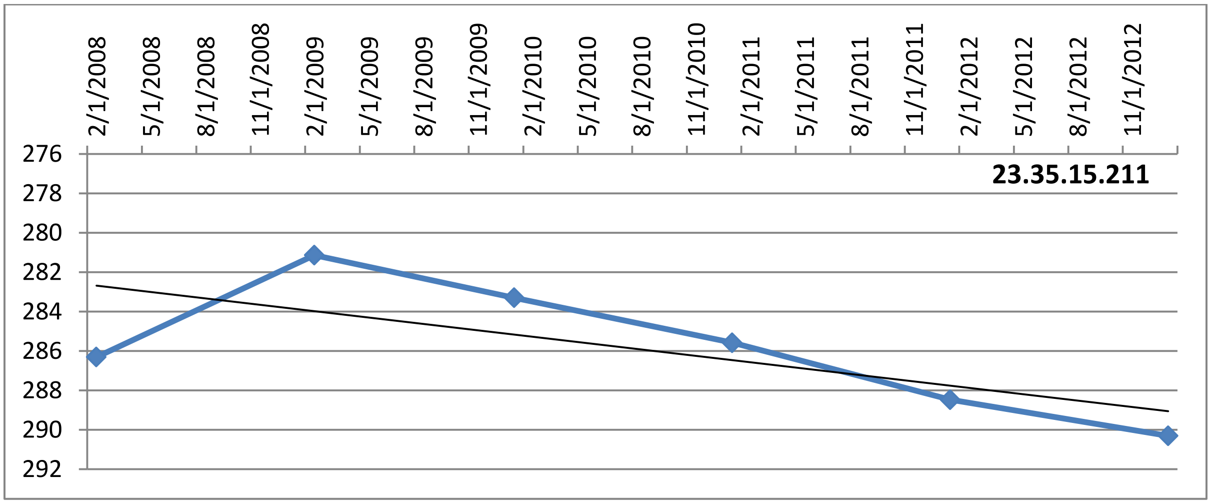
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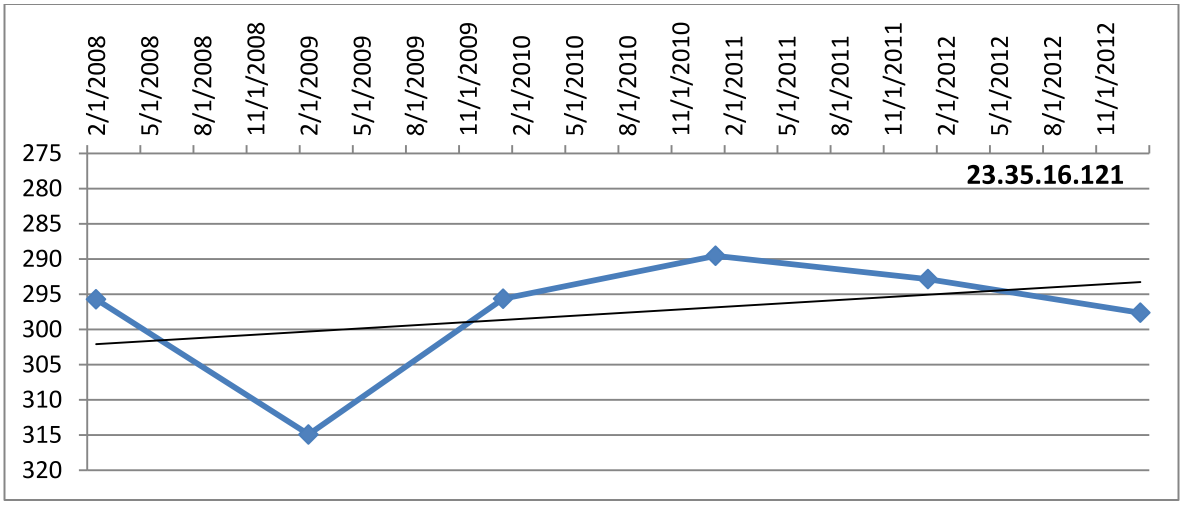
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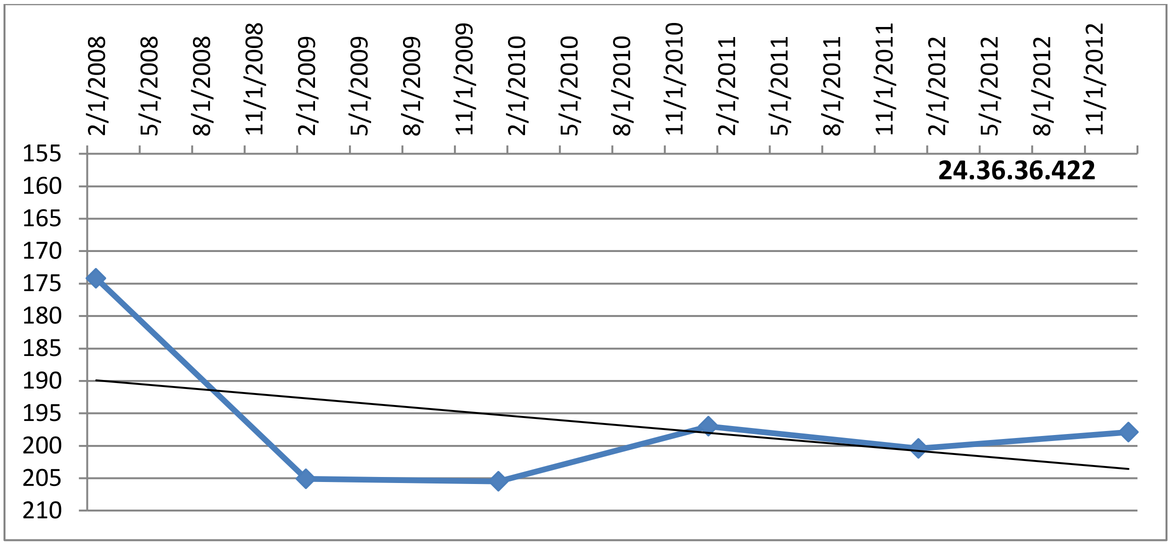
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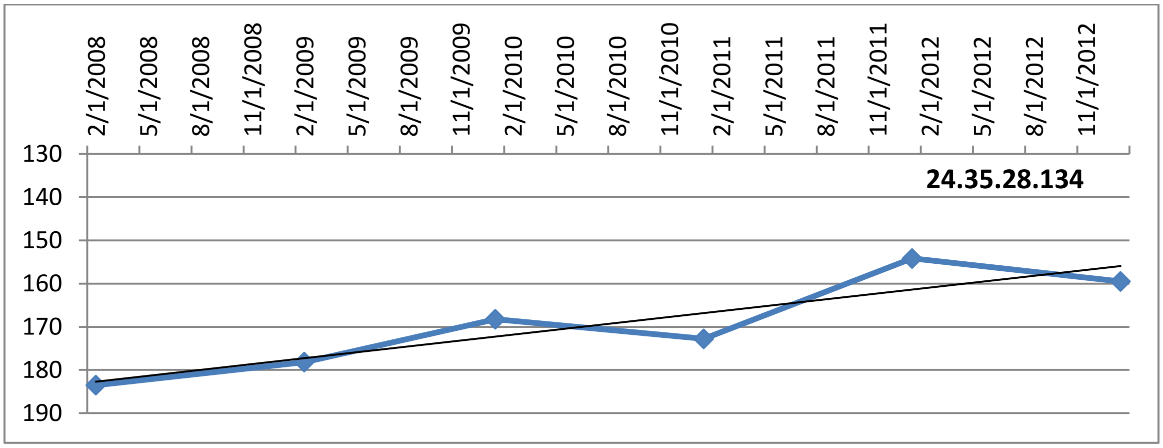
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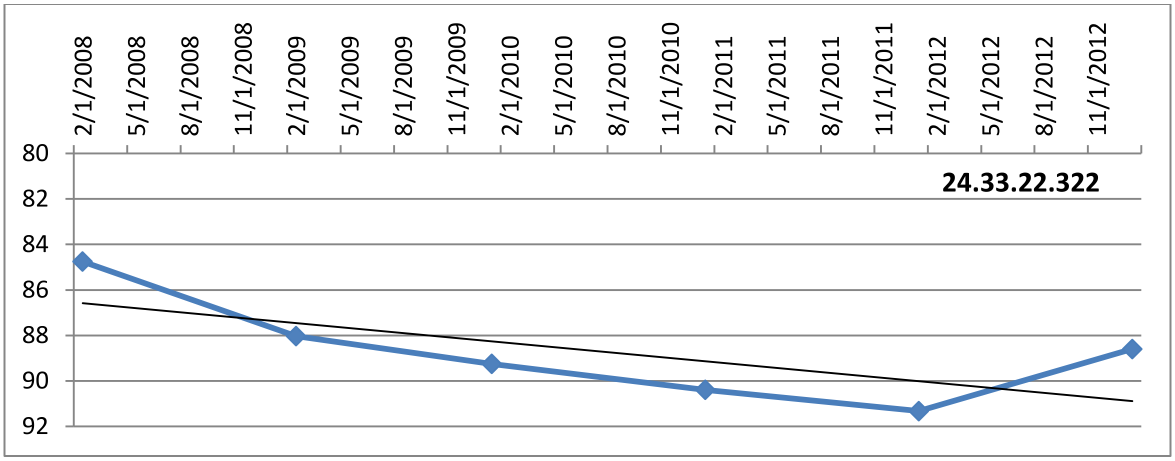

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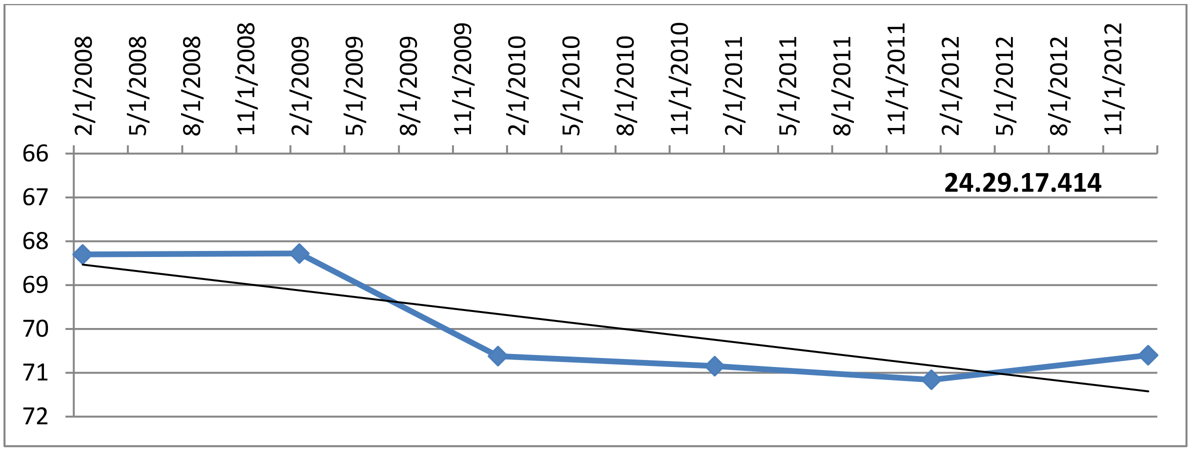

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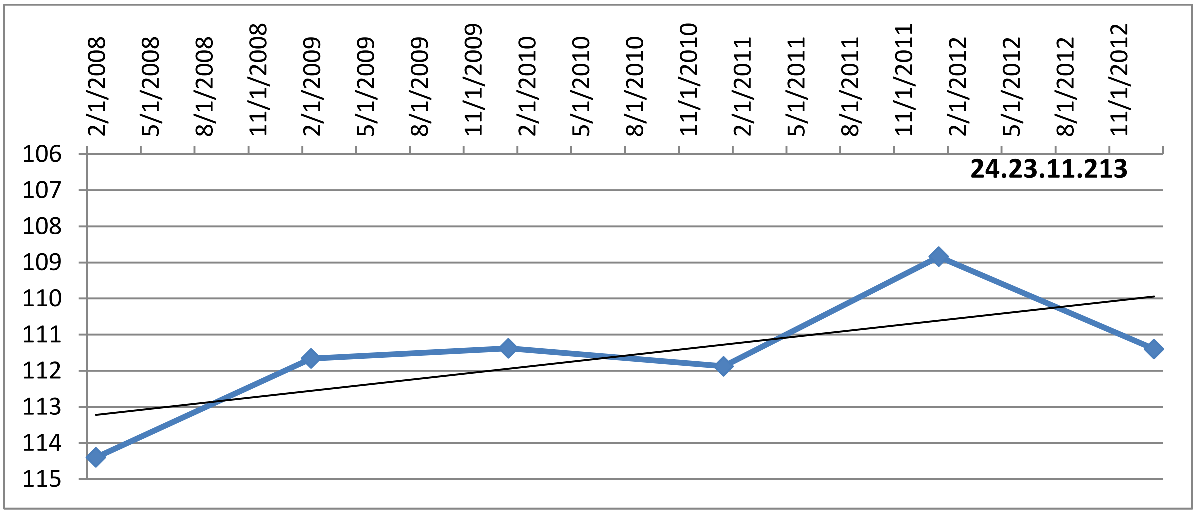

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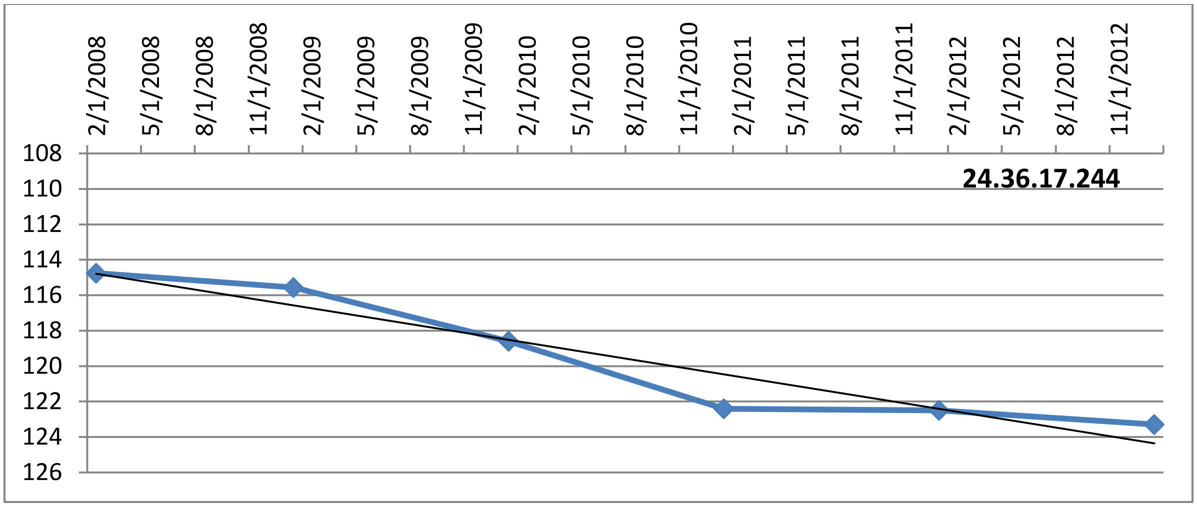
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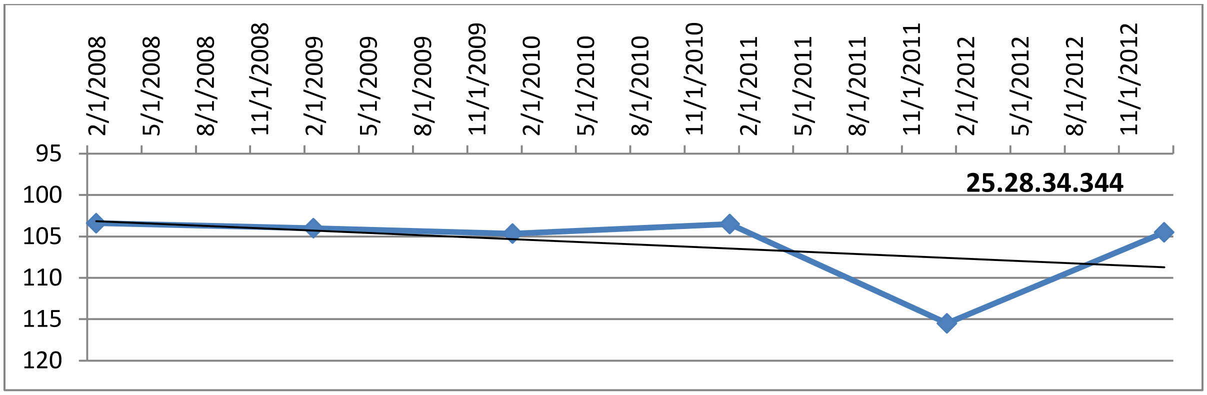
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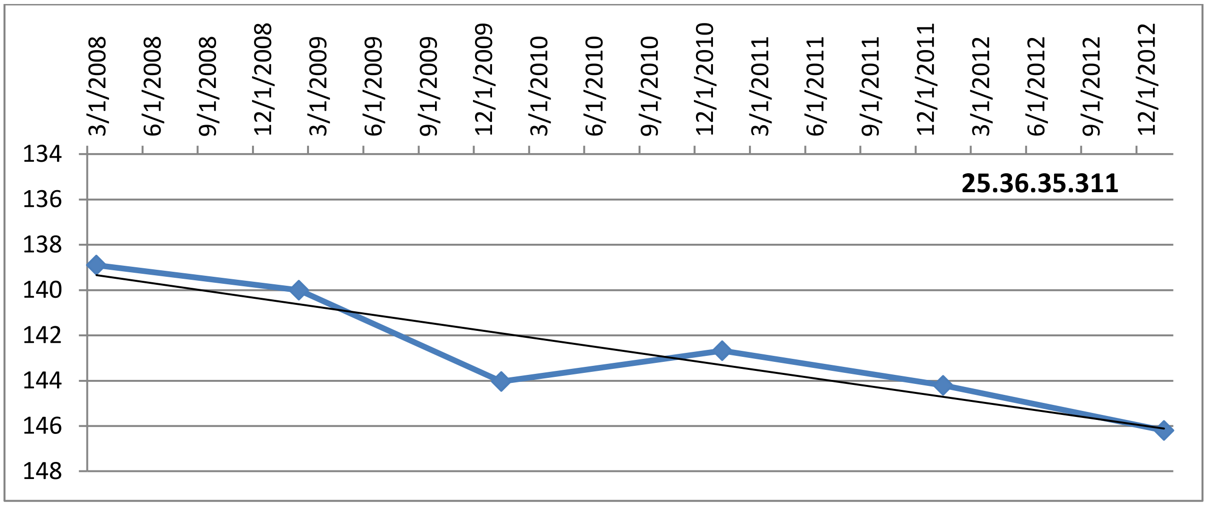
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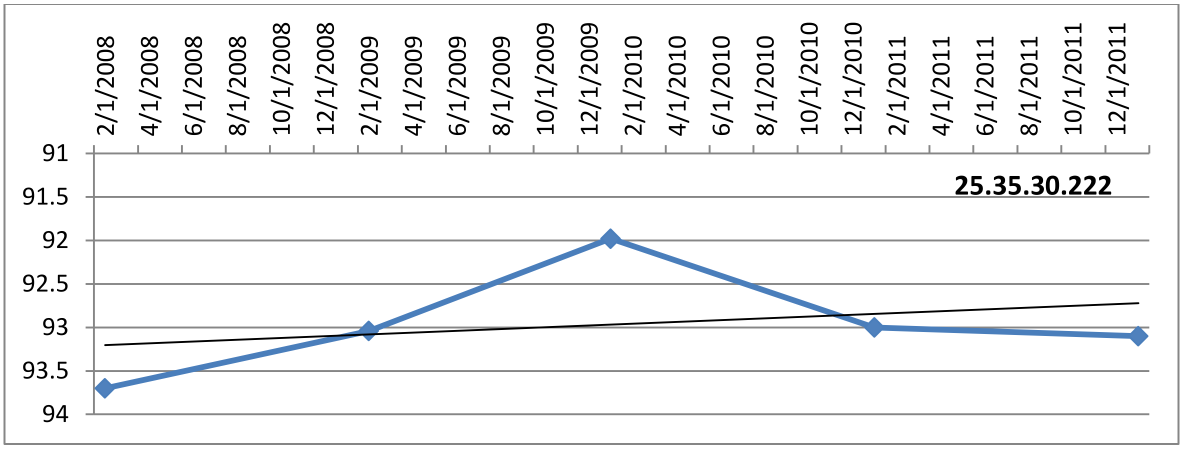
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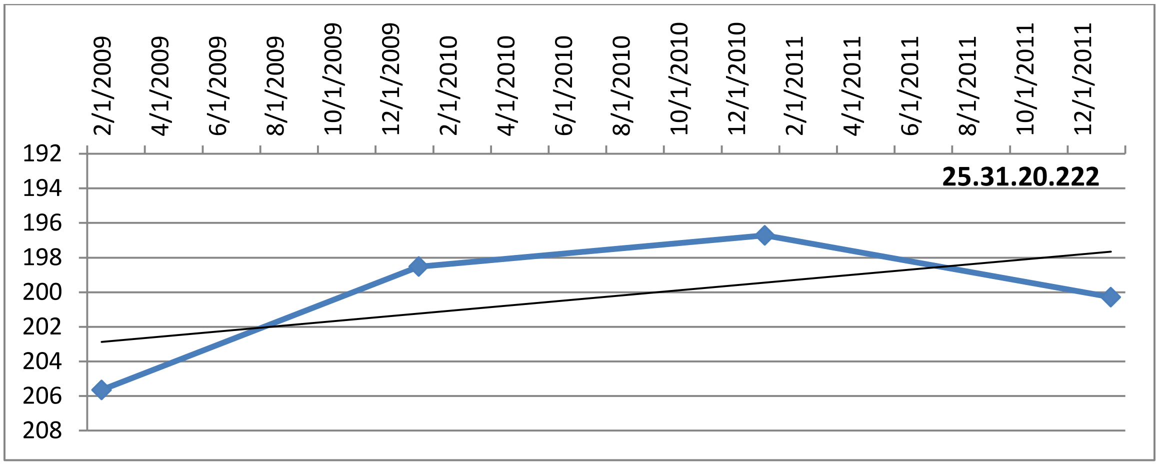
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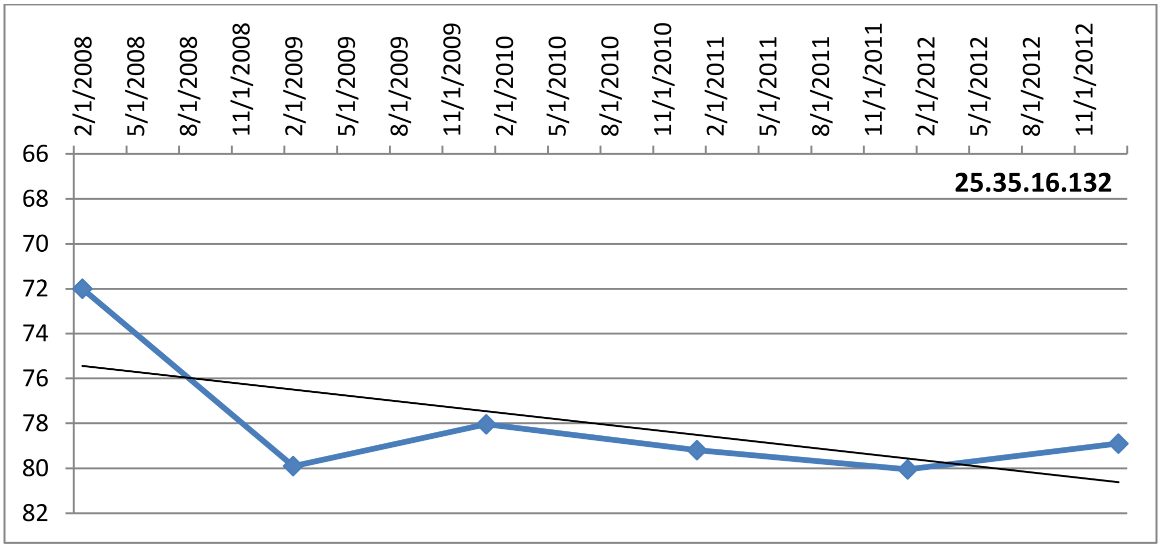
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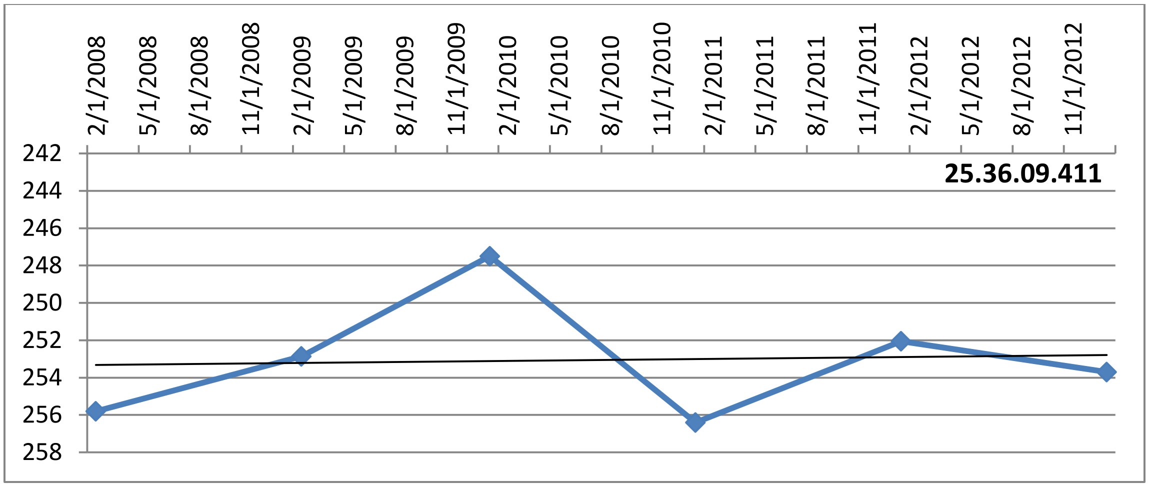
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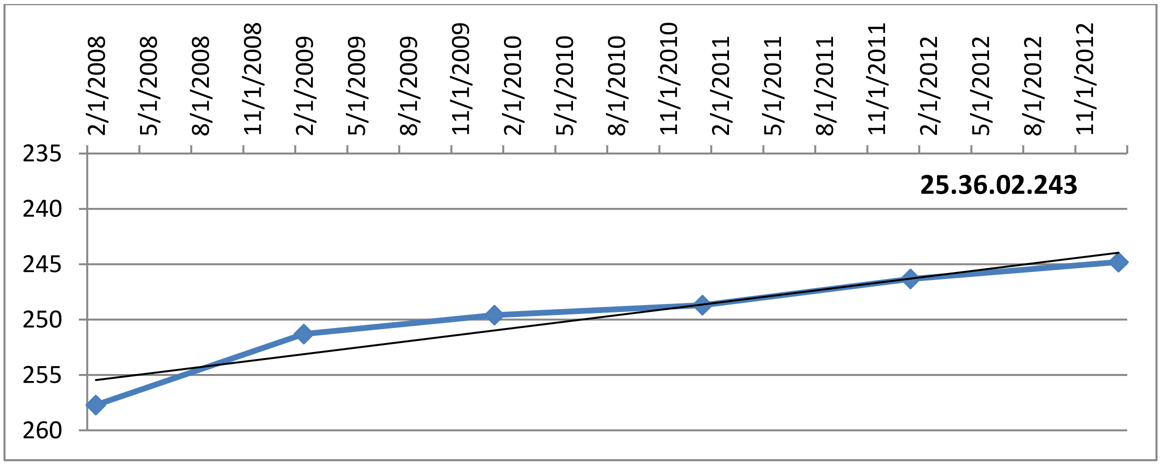
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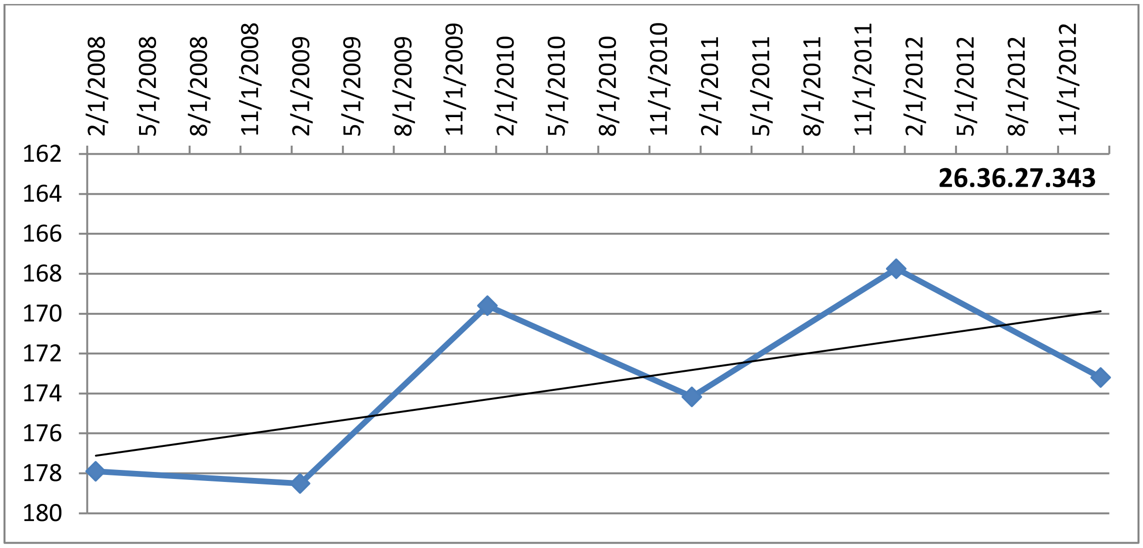
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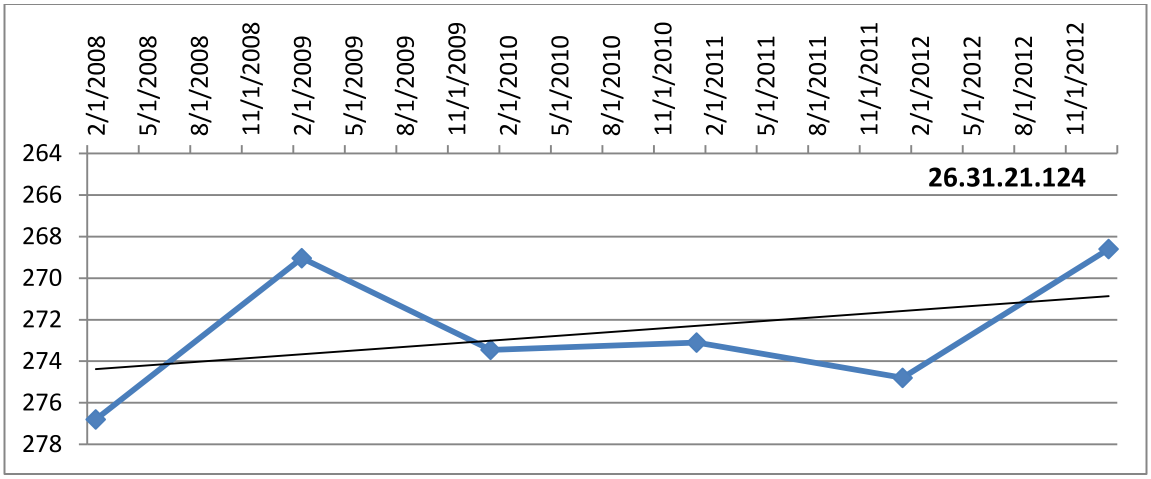
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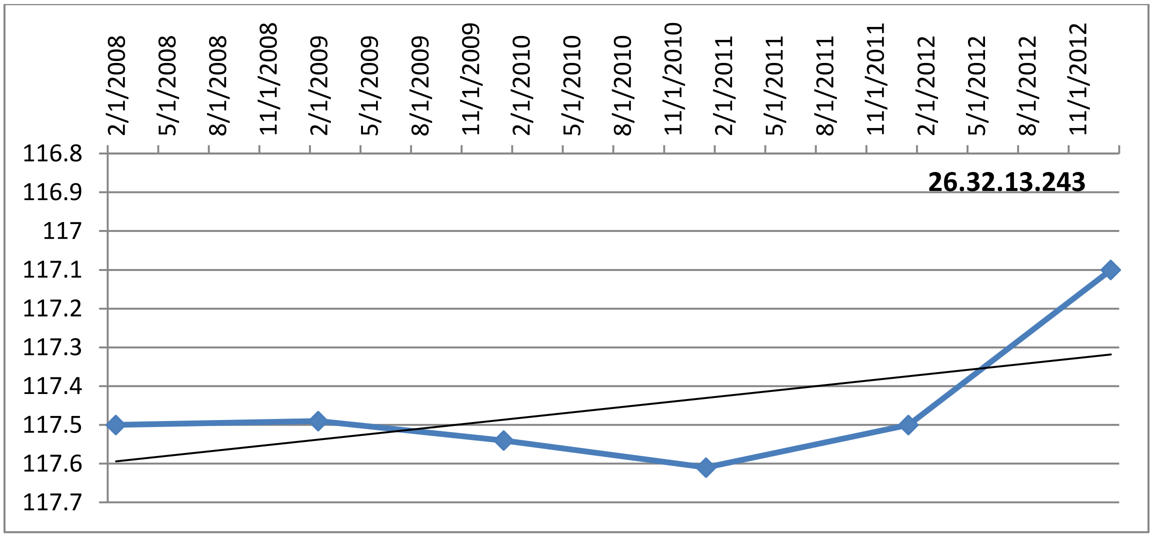
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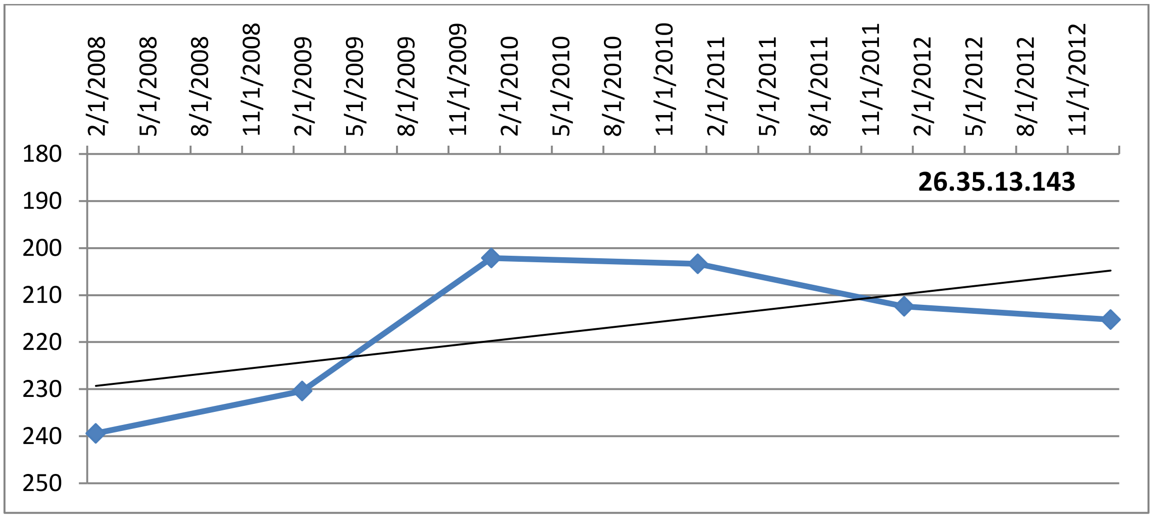
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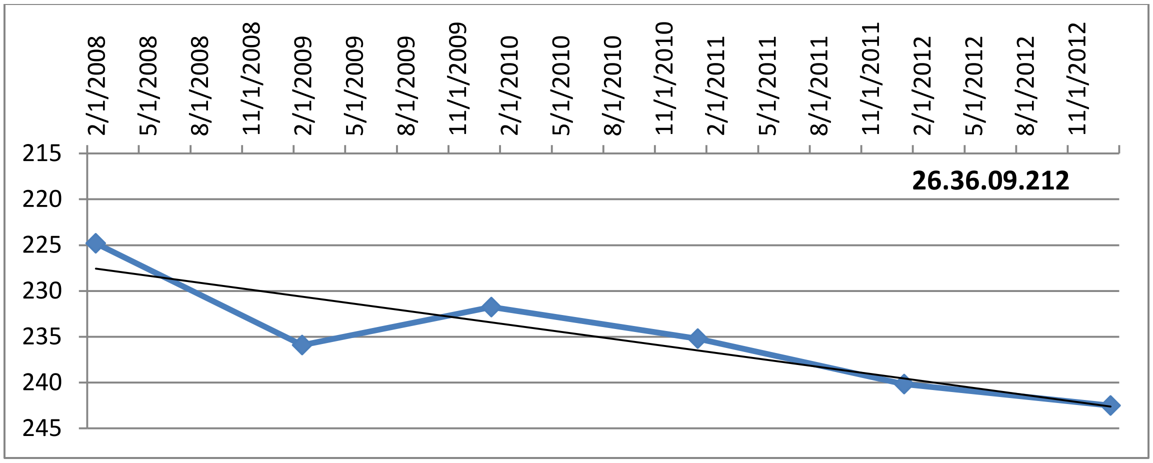
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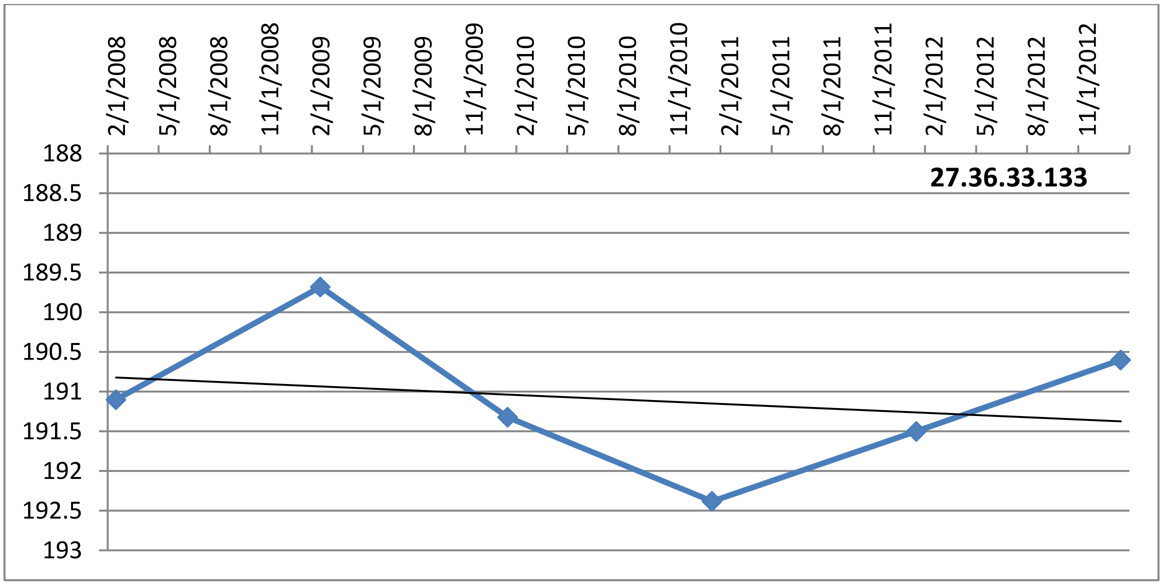
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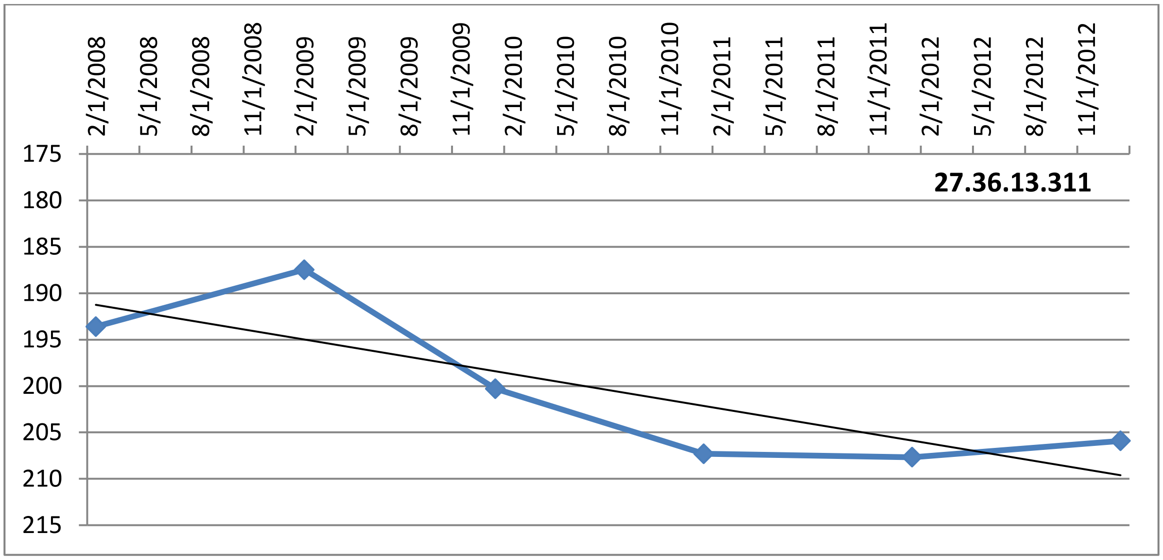
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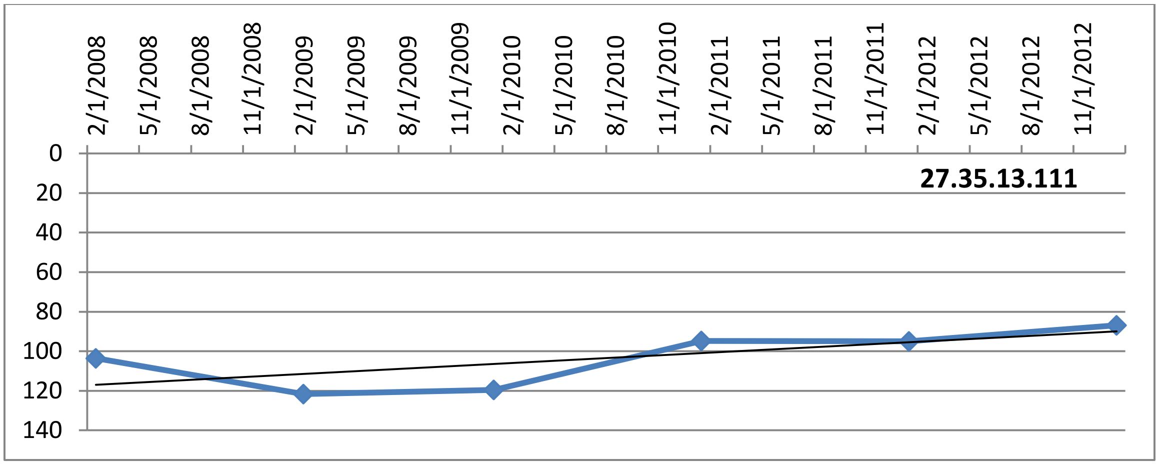
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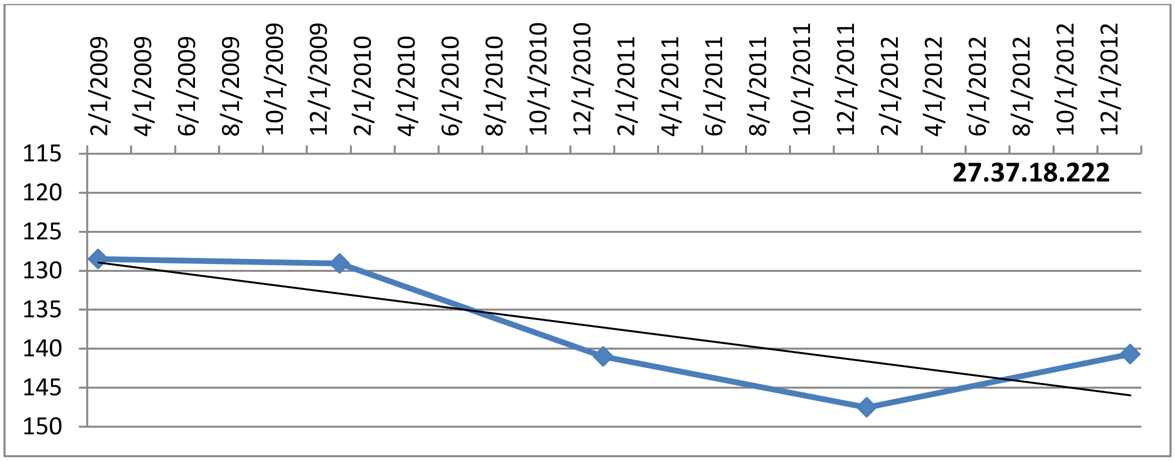
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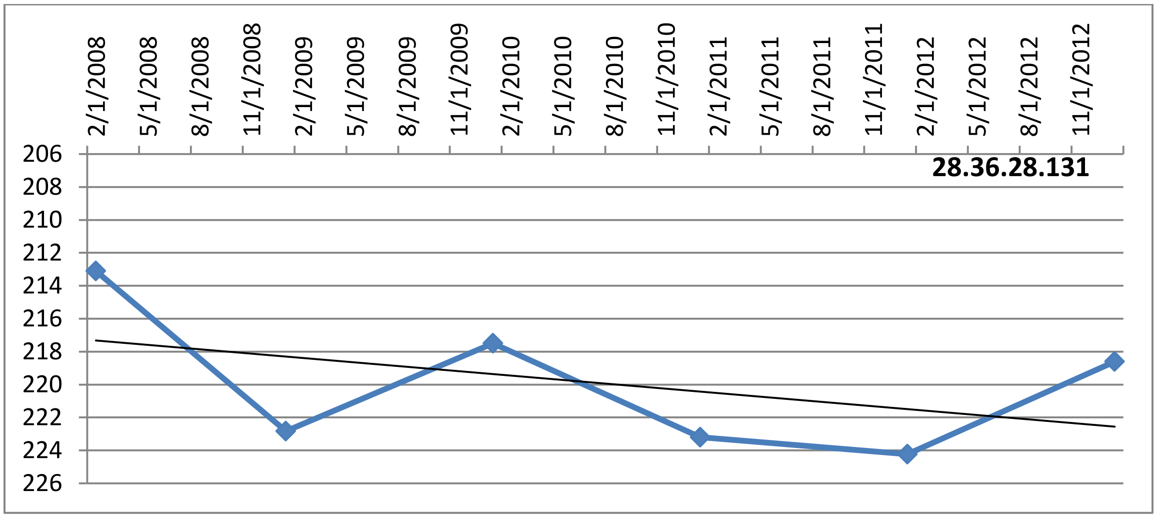
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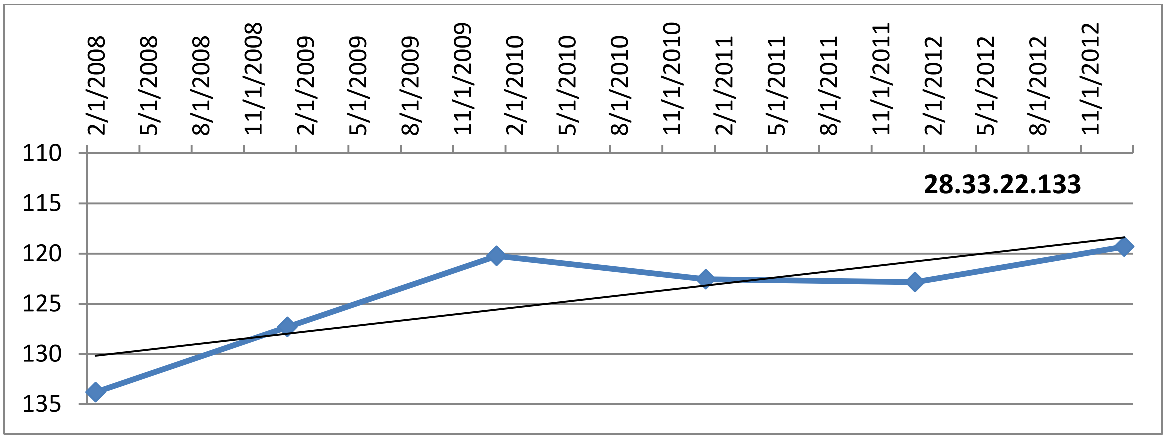
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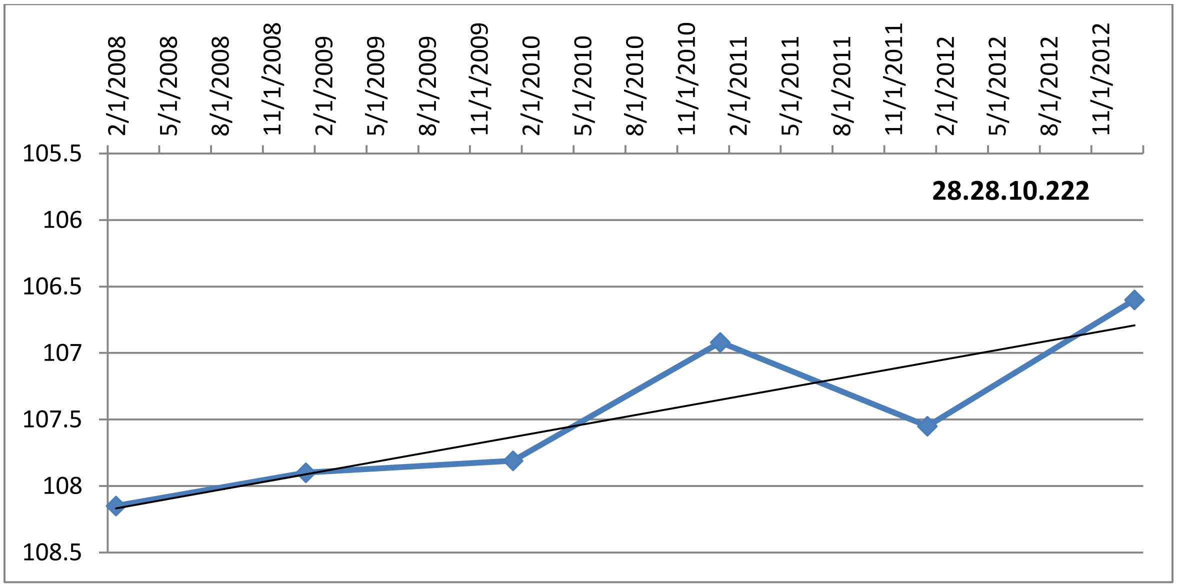
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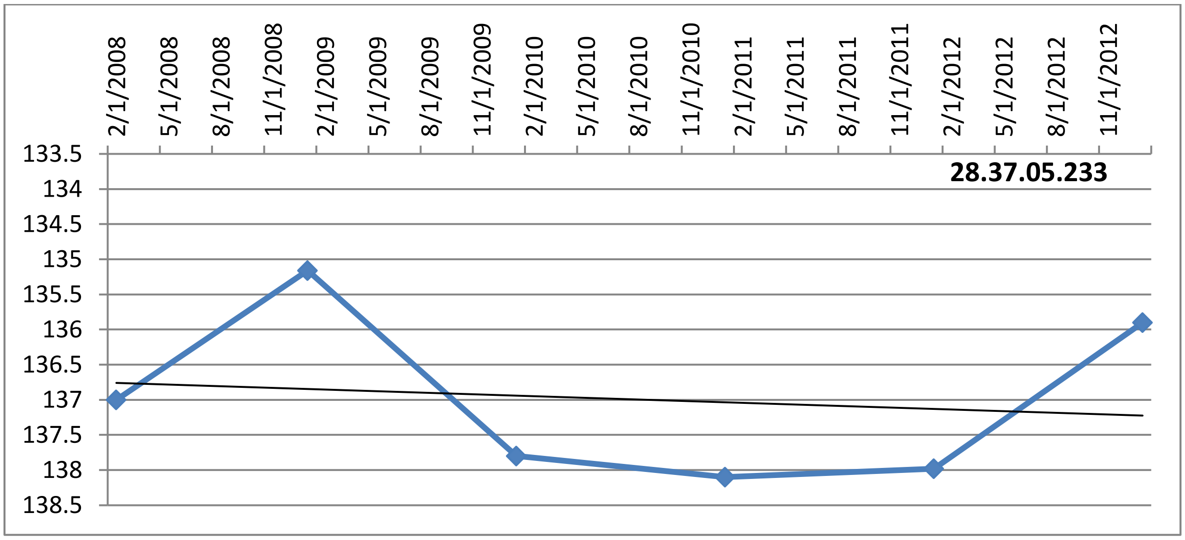
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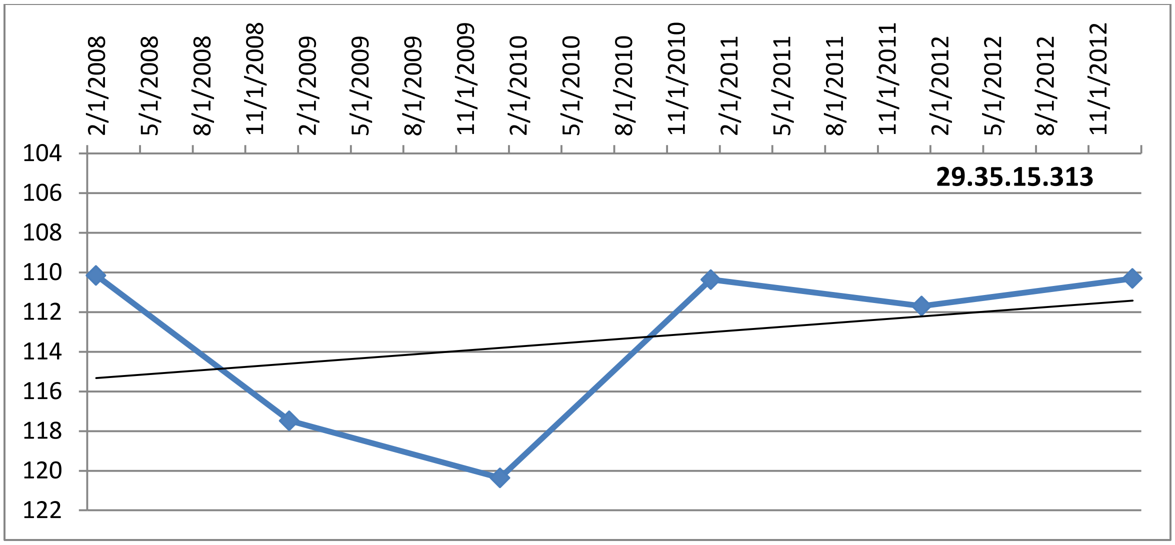
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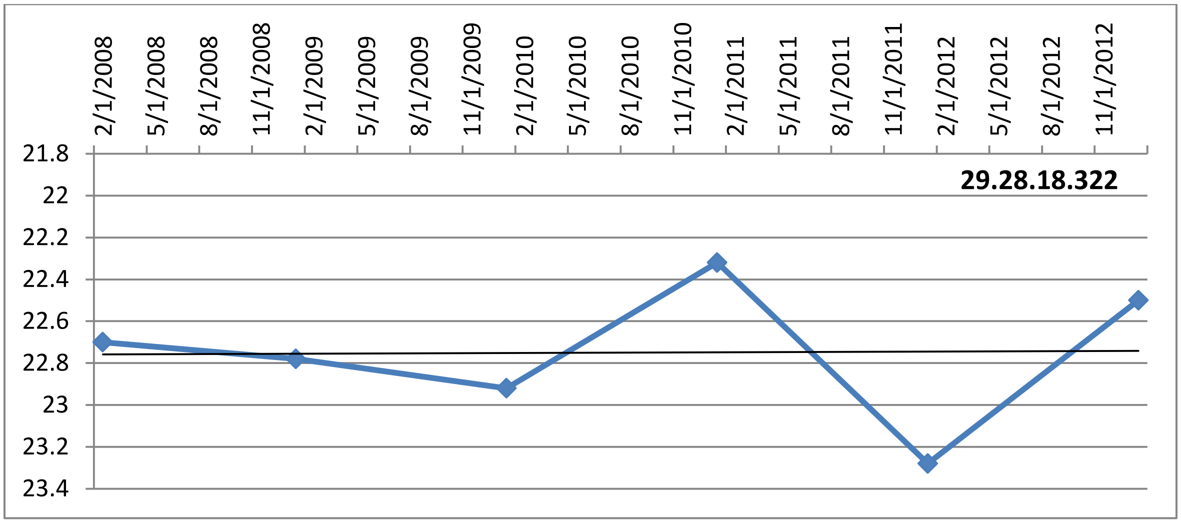
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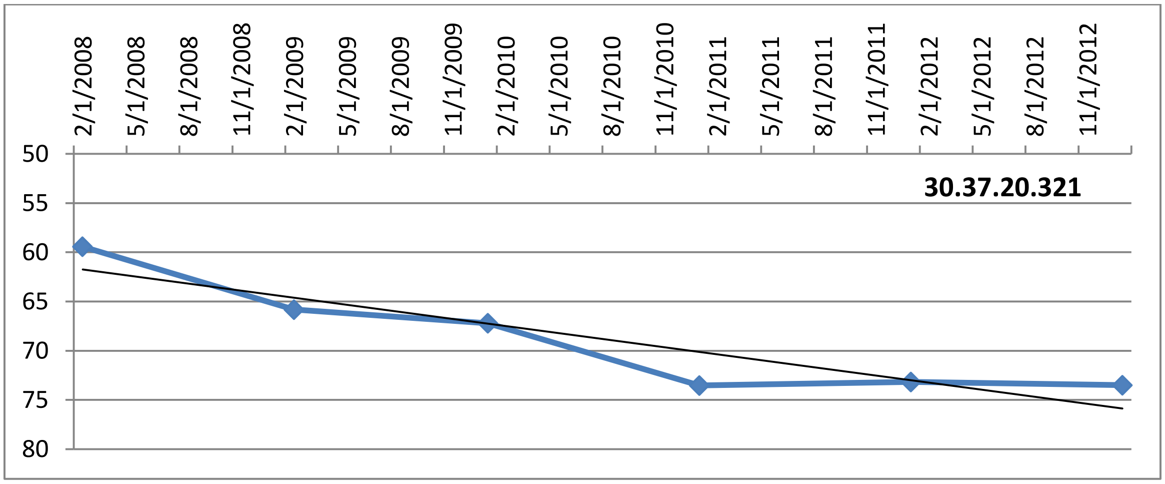
29.28.18.322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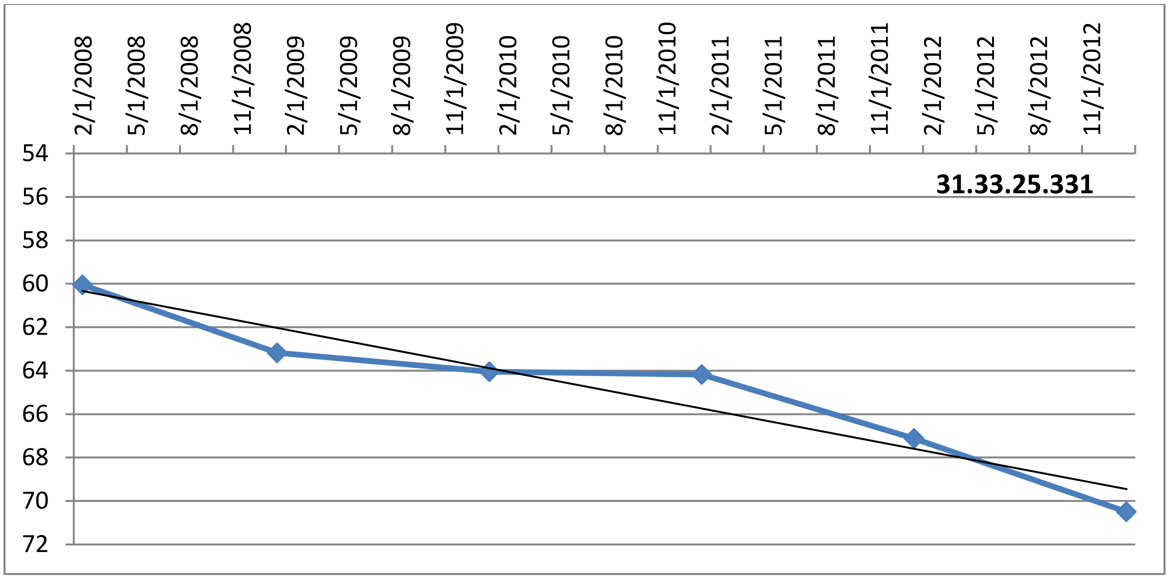
30.37.20.321



31.33.25.331
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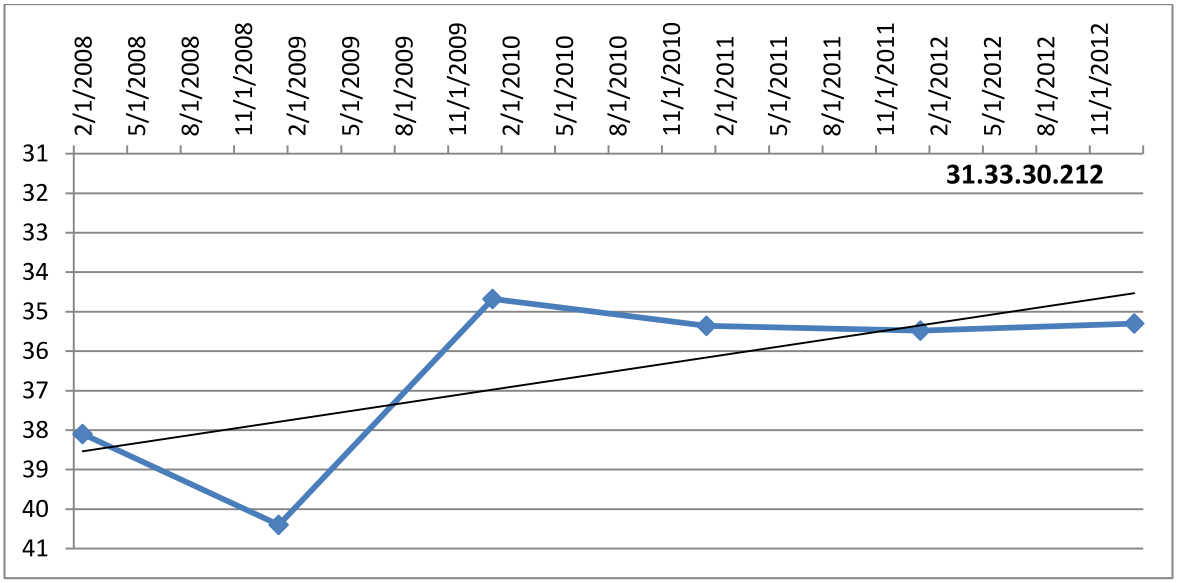

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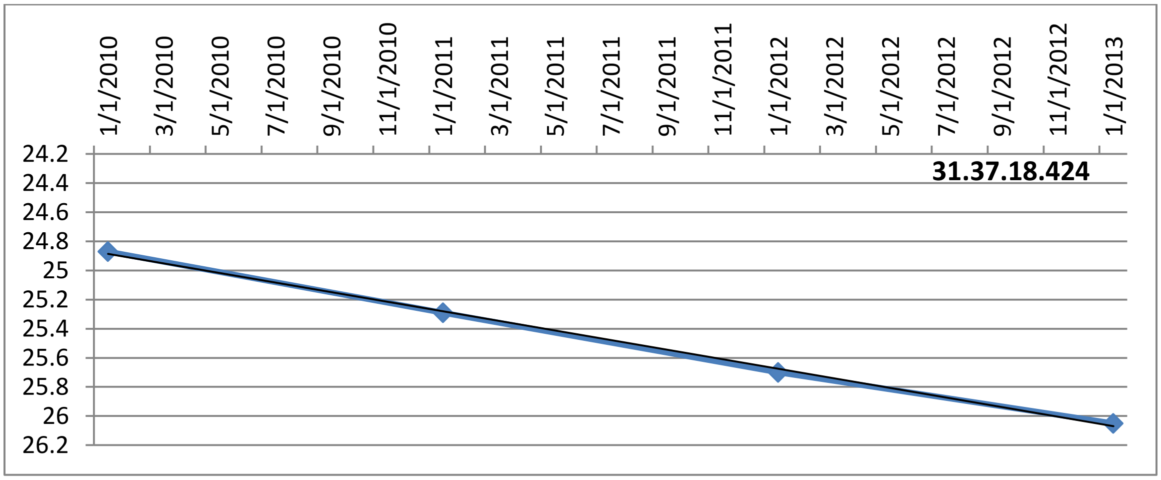

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24.2
24.4
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25.2
25.4
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26.2

Appendix II: January Static Water Level Measurements

Individual well static water level measurements from January 2008 through January 2013.

Local ID & Elevation	Dates Measured	Depth to Water	Change in Depth	Years Measured	Rate of Change
18N36E35.111	2/18/2008	270.6	1.4	6	0.233333
4465'	1/30/2009	273.3			
	1/5/2010	270.8			
	1/1/2011	275.99			
	1/3/2012	273.95			
	1/6/2013	269.2			
18N34E15.422	2/18/2008	114	8.7	6	1.45
4764'	1/30/2009	106.3			
	1/6/2010	105.2			
	1/7/2011	105.25			
	1/3/2012	106.38			
	1/6/2013	105.3			
19N34E32.133	2/18/2008	157.7	9.2	6	1.533333
4883'	1/30/2009	151.2			
	1/1/2010	151.8			
	1/1/2011	149.14			
	1/3/2012	150.54			
	1/6/2013	148.5			
19N36E23.244	2/6/2008	154.9	1.1	6	0.183333
4360'	1/30/2009	155.2			
	1/1/2010	153.13			
	1/1/2011	153.43			
	1/3/2012	154.8			
	1/6/2013	153.8			

20N35E11.333	2/18/2008	85.9	-23.4	6	-3.9
4558'	2/24/2009	81			
	1/10/2010	80.35			
	1/1/2011	103.91			
	1/7/2012	83.17			
	1/6/2013	109.3			
20N35E01.211	2/18/2008	92.4	1.61	5	0.322
	1/30/2009	90.3			
	1/20/2010	91.1			
	1/13/2011	94.55			
	1/3/2012	90.79			
21N36E35.122	2/24/2009	146.82	-11.38	5	-2.276
4450'	1/12/2010	159.24			
	1/14/2011	153.29			
	1/7/2012	159.74			
	1/6/2013	158.2			
21N35E01.224	2/18/2008	219	-9.5	5	-1.9
4570'	2/16/2009				
	1/11/2010	222.22			
	1/14/2011	229.05			
	1/2/2012	232.04			
	1/6/2013	228.5			
22N34E10.444	2/26/2008	115.8	-3.4	6	-0.56667
4765'	2/16/2009	117.96			
	1/11/2010	115.5			
	1/11/2011	120.3			
	1/3/2012	120.7			
	1/6/2013	119.2			
22N36E04.121	3/4/2008	192	-16.68	5	-3.336
4611'	2/9/2009	205.5			

	1/13/2010	189.04			
	1/13/2011	203.16			
	1/2/2012	208.68			
22N36E10.411	2/19/2008	308.2	-8.8	6	-1.46667
4558'	2/9/2009	310.51			
	1/13/2010	311.35			
	1/13/2011	314.23			
	1/2/2012	316.08			
	1/6/2013	317			
23N36E35.111	2/19/2008	301.8	-16.4	6	-2.73333
4611'	2/9/2009	315.44			
	1/11/2010	316.1			
	1/12/2011	318.1			
	1/2/2012	323.42			
	1/6/2013	318.2			
23N33E28.432	2/26/2008	71.8	-1.11	6	-0.185
5020'	2/16/2009	71.84			
	1/12/2010	72.77			
	1/15/2011	72.63			
	1/3/2012	73.2			
	1/6/2013	72.91			
23N35E29.122	2/26/2008	184.5	0.7	6	0.116667
4794'	2/24/2009	192.24			
	1/13/2010	189.32			
	1/15/2011	189.79			
	1/3/2012	188.1			
	1/6/2013	183.8			
23N36E23.341	2/19/2008	206.9	-8.84	6	-1.47333
4761'	2/9/2009	210.56			
	1/15/2010	212.52			
	1/20/2011	211.4			

	1/2/2012	211.91			
	1/6/2013	215.74			
23N34E16.442	2/26/2008	169.1	2.1	6	0.35
4925'	2/16/2009	176.74			
	1/14/2010	171.35			
	1/20/2011	170.1			
	1/3/2012	175.82			
	1/6/2013	167			
23N35E15.211	2/26/2008	286.3	-4	6	-0.66667
4797'	2/24/2009	281.13			
	1/25/2010	283.29			
	1/15/2011	285.58			
	1/3/2012	288.47			
	1/6/2013	290.3			
23N35E16.121	2/26/2008	295.7	-1.9	-6	0.316667
4812'	2/3/2009	314.9			
	1/12/2010	295.62			
	1/14/2011	289.52			
	1/3/2012	292.83			
	1/6/2013	297.6			
24N36E36.422	2/19/2008	174.2	-23.7	6	-3.95
4720'	2/13/2009	205.1			
	1/15/2010	205.48			
	1/13/2011	196.99			
	1/6/2012	200.42			
	1/6/2013	197.9			
24N35E28.134	2/27/2008	183.5	24	6	4
4643'	2/16/2009	178.17			
	1/15/2010	168.25			
	1/16/2011	172.79			
	1/3/2012	154.19			

	1/6/2013	159.5			
24N33E22.322	2/27/2008	84.75	-3.85	6	-0.64167
5410'	2/11/2009	88.03			
	1/15/2010	89.25			
	1/15/2011	90.39			
	1/4/2012	91.33			
	1/6/2013	88.6			
24N29E17.414	2/28/2008	68.3	-2.3	6	-0.38333
5760'	2/4/2009	68.28			
	1/16/2010	70.62			
	1/12/2011	70.85			
	1/4/2012	71.16			
	1/6/2013	70.6			
24N33E11.213	2/27/2008	114.4	3	6	0.5
5675'	2/4/2009	111.66			
	1/16/2010	111.38			
	1/15/2011	111.88			
	1/6/2012	108.84			
	1/6/2013	111.4			
24N36E.12.111	8/16/2007	137.64			
4668'	2/5/2008	146.07			
	8/12/2008	NA			
	2/5/2009	DRY - DROPPED WELL			
24N36E17.244	2/16/2008	114.76	-8.54	6	-1.42333
4707'	1/17/2009	115.57			
	1/15/2010	118.6			
	1/23/2011	122.41			
	1/6/2012	122.5			
	1/6/2013	123.3			

25N28E34.344	2/28/2008	103.4	-1.1	6	-0.18333
5960'	2/4/2009	104			
	1/14/2010	104.65			
	1/13/2011	103.5			
	1/6/2012	115.5			
	1/6/2013	104.5			
25N36E.35.311	3/5/2008	138.9	-7.3	6	-1.21667
4682'	2/13/2009	140.01			
	1/14/2010	144.04			
	1/15/2011	142.68			
	1/6/2012	144.21			
	1/6/2013	146.2			
25N35E30.222	2/27/2008	93.7	0.6	5	0.12
5007'	2/13/2009	93.04			
	1/13/2010	91.98			
	1/23/2011	93			
	1/6/2012	93.1			
25N31E20.222	2/4/2009	205.65	5.36	4	1.34
	1/13/2010	198.52			
	1/13/2011	196.72			
	1/4/2012	200.29			
25N35E16.132	2/27/2008	72	-6.9	6	-1.15
5045'	2/26/2009	79.9			
	1/14/2010	78.04			
	1/12/2011	79.19			
	1/6/2012	80.05			
	1/6/2013	78.9			
25N36E09.411	2/27/2008	255.8	2.1	6	0.35
4850'	2/11/2009	252.86			
	1/14/2010	247.5			
	1/13/2011	256.4			

	1/6/2012	252.05			
	1/6/2013	253.7			
25N36E.02.243	2/27/2008	257.7	12.9	6	2.15
4810'	2/11/2009	251.29			
	1/15/2010	249.58			
	1/14/2011	248.68			
	1/6/2012	246.31			
	1/6/2013	244.8			
26N36E.27.343	2/27/2008	177.9	4.7	6	0.783333
4810'	2/11/2009	178.51			
	1/15/2010	169.6			
	1/13/2011	174.17			
	1/6/2012	167.75			
	1/6/2013	173.2			
26N31E.21.124	2/28/2008	276.8	8.2	6	1.366667
6010'	2/4/2009	269.04			
	1/21/2010	273.45			
	1/14/2011	273.1			
	1/4/2012	274.8			
	1/6/2013	268.6			
26N32E.13.243	2/28/2008	117.5	0.4	6	0.066667
5600'	2/4/2009	117.49			
	1/23/2010	117.54			
	1/12/2011	117.61			
	1/4/2012	117.5			
	1/6/2013	117.1			
26N35E.13.143	2/2/2008	239.4	24.2	6	4.033333
4850'	2/4/2009	230.38			
	1/21/2010	202.1			
	1/12/2011	203.34			
	1/6/2012	212.38			

	1/6/2013	215.2			
26N36E.09.212	2/2/2008	224.8	-17.7	6	-2.95
4792'	2/11/2009	235.9			
	1/12/2010	231.76			
	1/12/2011	235.2			
	1/6/2012	240.16			
	1/6/2013	242.5			
27N36E.33.133	2/28/2008	191.1	0.5	-6	-0.08333
4892'	2/11/2009	189.68			
	1/12/2010	191.32			
	1/11/2011	192.38			
	1/6/2012	191.5			
	1/6/2013	190.6			
27N36E13.311	2/29/2008	193.6	-12.3	6	-2.05
4776'	2/11/2009	187.47			
	1/8/2010	200.29			
	1/2/2011	207.3			
	1/6/2012	207.66			
	1/6/2013	205.9			
27N35E.13.111	2/2/2008	103.6	16.7	6	2.783333
4963'	2/28/2009	121.66			
	1/5/2010	119.54			
	1/14/2011	94.8			
	1/5/2012	95.02			
	1/6/2013	86.9			
27N37E.18.222	2/9/2009	128.5	-12.2	5	-2.44
4718'	1/9/2010	129.08			
	1/15/2011	141			
	1/6/2012	147.52			
	1/6/2013	140.7			

28N36E28.131	2/2/2008	213.1	-5.5	6	-0.91667
4905'	1/31/2009	222.83			
	1/12/2010	217.49			
	1/3/2011	223.2			
	1/5/2012	224.23			
	1/6/2013	218.6			
28N33E.22.133	2/10/2008	133.8	14.5	6	2.416667
5546'	1/21/2009	127.3			
	1/6/2010	120.22			
	1/7/2011	122.55			
	1/4/2012	122.83			
	1/6/2013	119.3			
28N28E.10.222	2/28/2008	108.15	1.55	6	0.258333
6814'	1/31/2009	107.9			
	1/6/2010	107.81			
	1/20/2011	106.92			
	1/4/2012	107.55			
	1/6/2013	106.6			
28N37E.05.233	2/2/2008	137	1.1	6	0.183333
4811'	1/30/2009	135.16			
	1/7/2010	137.8			
	1/8/2011	138.1			
	1/5/2012	137.98			
	1/6/2013	135.9			
29N35E.15.313	2/10/2008	110.15	-0.15	6	-0.025
5180'	1/31/2009	117.48			
	1/7/2010	120.36			
	1/8/2011	110.36			
	1/4/2012	111.69			
	1/6/2013	110.3			

29N28E.18.322	2/28/2008	22.7	0.2	6	0.033333
6890'	1/31/2009	22.78			
	1/9/2010	22.92			
	1/6/2011	22.32			
	1/4/2012	23.28			
	1/6/2013	22.5			
30N37E20.321	2/2/2008	59.42	-14.08	6	-2.34667
4720'	2/3/2009	65.82			
	1/7/2010	67.2			
	1/8/2011	73.53			
	1/5/2012	73.17			
	1/6/2013	73.5			
31N33E25.331	2/10/2008	60.05	-10.45	6	-1.74167
5372'	1/31/2009	63.18			
	1/8/2010	64.05			
	1/9/2011	64.18			
	1/5/2012	67.12			
	1/6/2013	70.5			
31N33E.30.212	2/10/2008	38.1	2.8	6	0.466667
5120'	1/31/2009	40.4			
	1/8/2010	34.68			
	1/8/2011	35.36			
	1/5/2012	35.48			
	1/6/2013	35.3			
31N37E.18.424	1/6/2010	24.87	-1.18	4	-0.295
4356'	1/5/2011	25.29			
	1/5/2012	25.7			
	1/6/2013	26.05			

Appendix III: Union County Well Cuttings 2013

Texaco "CT" Click NCT-1 (34-28N-28E, TD: 3183')

0-40'	No samples.
40-50'	Medium gray basalt. Abundant olivine.
50-60'	Ditto 40-50'.
60-70'	Orange-red siltstone with common loose fine to coarse quartz grains, subrounded, +HCl. Medium gray basalt. [90% silt., 10% basalt] →*top of To, baked zone*
70-80'	Ditto 60-70'.
80-90'	Ditto 60-70'.
90-100'	Ditto 60-70'. [95% silst., 5% basalt] → *base of baked zone*
100-110'	Pale orange loose sand, fine to medium grained, subrounded, moderately well sorted, 100% quartz.
110-120'	Pale tan loose sand, very fine to fine grained, subangular to subround, moderately well sorted, 80% Q, 20% calcrete.
120-130'	Pale tan loose sand, very fine to fine grained, some coarse grains, subangular to subround, moderately well sorted, 90% Q, 10% calcrete.
130-140'	Pale tan loose sand, fine to coarse grained, subround to subangular, moderately sorted, 95% Q, 5% calcrete. Rare muscovite and biotite (contaminant from basalt?)
140-150'	Ditto 130-140'. 98% Q, 2% calcrete.
150-160'	Pale tan loose sand, very fine to very coarse grained, subround to subangular, poorly sorted, 90% Q, 10% L (quartzite, limestone, granite, etc.).
160-170'	Ditto 150-160'.
170-180'	Pale tan siltstone (high lithic percentage). Pale tan loose sand, fine to very coarse grained, subangular, poorly sorted, 100% Q. [70% silt., 30% loose sand]
180-190'	Loose gravel. Includes basalt, limestone, siderite, quartzite, quartz, calcrete. Some loose quartz sand, medium to coarse grained, subrounded, poorly sorted, 100% Q. [80% gravel, 20% sand]
190-200'	Loose gravel (smaller than 180-190'). Includes limestone, siderite, quartzite, basalt, etc. Loose sand, medium to very coarse grained, angular to subangular, poorly sorted, 100% Q. [50% gravel, 50% sand]
200-210'	Ditto 180-190'.
210-220'	Medium gray shale, +HCl. Loose gravel. Includes siltstone, quartzite, sandstone, limestone, quartz, etc. [70% shale, 30% gravel]. → *Top of Kg*
220-230'	Medium gray shale, +HCl. Very pale orange siltstone, -HCl. Loose gravel. Includes quartz, granite, quartzite, calcrete. [70% shale, 15% silt., 15% gravel]
230-240'	Medium gray shale, +HCl. Pale tan siltstone, +HCl. [85% shale, 15% silt.]
240-250'	Ditto 230-240'. Siltstone also pale red.
250-260'	Medium gray shale, +HCl.

260-270’	Medium gray shale, +HCl. Pale tan and pale red siltstone, +HCl. [95% shale, 5% silt.]
270-280’	Medium gray shale, +HCl. Pale red siltstone, +HCl. [95% shale, 5% silt.]
280-290’	Medium gray shale, +HCl. Pale tan siltstone with manganese growths, +HCl. [95% shale, 5% silt.]
290-300’	Medium gray shale, +HCl. Pale tan siltstone with selenite crystals on one side, +HCl. Very pale gray micrite. [95% shale, 3% silt., 2% limest.]
300-310’	Medium gray shale, +HCl. Two pebbles: gold siltstone, dark gray micrite.
310-320’	Medium gray shale, +HCl. Pale red siltstone, +HCl. [98% shale, 2% silt.]
320-330’	Dark gray shale, less well indurated, +HCl.
330-340’	Dark gray shale/mudstone, not well indurated, +HCl.
340-350’	Dark gray shale/mudstone, +HCl. Pale red and pale tan siltstone, +HCl. [95% shale, 5% silt.]
350-360’	Dark gray mudstone/shale. +HCl.
360-370’	Dark gray shale, well indurated, +HCl. Pale red and pale tan siltstone, +HCl. [95% shale, 5% silt.]
370-380’	Medium gray shale/mudstone, -HCl. Pale yellow quartz wacke, medium grained, subrounded, 100% Q, >15% clay matrix. [90% shale, 10% sandst.] → *top of Kd*
380-390’	Medium gray shale, -HCl. Pale yellow, pale red and pale tan siltstone, +HCl. Pale yellow quartz wacke, medium grained, subrounded, 100% Q, >15% clay matrix. [60% shale, 30% silt., 10% sand.]
390-400’	Medium gray shale, +HCl. Very pale tan quartz arenite, fine to medium grained, subangular to subround, well sorted, 100% Q, +HCl. Pale red and pale yellow siltstone, +HCl. [50% shale, 30% sandst., 20% silt.]
400-410’	Ditto 390-400’. [70% shale, 25% silt., 5% sandst.]
410-420’	Medium gray shale, -HCl. Medium gray quartz wacke/arenite, fine grained, subrounded, well worted, 100% Q, ±15% clay matrix, -HCl. Very pale tan quartz arenite, fine to medium grained, subangular to subround, well sorted, 100% Q, +HCl. Pale red and pale yellow siltstone, +HCl. [50% shale, 20% yellow sandst., 15% gray sandst., 15% silt.]
420-430’	Pale gray quartz arenite, fine grained, subround, well sorted, 100% Q, -HCl. Medium gray shale/mudstone, -HCl. [60% sandst., 40% shale]
430-440’	Very pale gray to gray quartz arenite, fine grained, subround, well sorted, 100% Q, -HCl. Medium gray shale, well indurated, -HCl. [70% sandst., 30% shale]
440-450’	Ditto 430-440’. Pale gray sandstone sometimes borderline wacke. [50% sandst., 50% shale]
450-460’	Ditto 430-440’.
460-470’	Ditto 430-440’. [75% sandst., 25% shale]
470-480’	Very pale gray to gray quartz arenite, fine grained, subround, well sorted, 100% Q, -HCl. Medium gray shale, well indurated, -HCl. Pale yellow and pale red siltstone, +HCl. [70% sandst., 25% shale, 5% silt.]

480-490’	Ditto 470-480’. Hematite cement common in gray sandstone.
490-500’	Ditto 480-490’.
500-510’	Very pale gray to gray quartz arenite, fine grained, subround, well sorted, 100% Q, -HCl. Medium gray shale, well indurated, -HCl. [80% sandst., 20% shale]
510-520’	Very pale gray to gray quartz arenite, fine grained, subround, well sorted, 100% Q, -HCl. Medium gray shale, well indurated, -HCl. Pale yellow siltstone, +HCl. [75% sandst., 20% shale, 5% silt.]
520-530’	Very pale gray to gray quartz arenite, fine grained, subround, well sorted, 100% Q, -HCl. Medium gray shale, well indurated, -HCl. Pale yellow and pale red siltstone, +HCl. [70% sandst., 25% shale, 5% silt.]
530-540’	Ditto 520-530’. Hematite cement common in gray sandstone.
540-550’	Ditto 530-540’.
550-560’	Ditto 530-540’.
560-570’	Pale greenish gray siltstone, -HCl. Very pale gray to gray quartz arenite, fine grained, subround, well sorted, 100% Q, -HCl. Medium gray shale, well indurated, -HCl. Pale yellow and pale red siltstone, +HCl. [70% green siltst., 15% gray sandst., 10% gray shale, 5% red and yellow silt.] → *Top of Glencairn*
570-580’	Ditto 560-570’.
580-590’	Ditto 560-570’ plus very pale gray quartz arenite, fine grained, subrounded, well sorted, 100% Q, silica cemented, -HCl. Small pebble of pyrite. [55% green silt., 30% white sandst., 15% gray sandst., shale and red and yellow siltst.]
590-600’	Ditto 580-590’.
600-610’	Ditto 580-590’. [25% green silt., 20% white sandst., 20% red and yellow siltst., 30% gray and yellow arenite, 5% gray shale]
610-620’	Pale greenish gray siltstone, -HCl. Reddish-brown mudstone, -HCl. Very pale gray quartz arenite, fine grained, subrounded, well sorted, 100% Q, silica cemented, -HCl. [40% green silt., 40% red mudst., 20% white sandst.]
620-630’	Ditto 610-620’. [45% green silt., 45% red mudst., 10% white sandst.]
630-640’	Ditto 610-620’.
640-650’	Ditto 610-620’. [45% green siltst., 30% white sandst., 25% red mudst.]
650-660’	Ditto 610-620’. [50% green siltst., 45% white sandst., 5% red mudst.]
660-670’	Ditto 640-650’ plus dark gray shale (<5% of the assemblage).
670-680’	Ditto 640-650’. Some of the red mudst. is silica cemented to near quartzite.
680-690’	Ditto 640-650’.
690-700’	Ditto 600-610’.

Amoco Prod. #1 State EW (3-26N-29E, TD: 2163’)

0-150’	No samples.

150-160’	Dark gray to black basalt (some vesicular) and obsidian. Pale orange siltstone, +HCl. [70% basalt, 30% silt.]
160-190’	No samples.
190-200’	Dark gray basalt, some vesicular, abundant olivine. (Two envelopes, both contain same material.)
200-210’	Dark gray basalt, some vesicular, abundant olivine. Very pale orange siltstone, +HCl. [60% basalt, 40% silt.]
210-220’	Ditto 200-210’.
220-230’	No samples.
230-240’	Very pale tan loose muddy sand. Fine to medium grained, subrounded to subangular, moderately well sorted, 100% Q. → *Top of To*
240-250’	Ditto 230-240’.
250-260’	Ditto 200-210’. (Two flows? Samples mislabeled?)
260-270’	Dark gray vesicular basalt. Medium gray shale, + HCl. [70% basalt, 30% shale]
270-280’	A. Pale green and pale red mudstone, + HCl. Very pale red micaceous siltstone, -HCl. [60% red and green mudstone, 40% silt.] B. Medium gray shale, +HCl. Dark gray vesicular basalt. Pale orange siltstone, +HCl. [45% shale, 50% basalt, 5% silt.] (two envelopes. B probably above A.)
280-290’	A. Pale tan loose sand, fine to medium grained, subround, moderately well sorted, 85% Q, 15% calcrete, muddy. B. Gray shale, +HCl. Basalt. Pale yellow siltstone, +HCl. [50% shale, 40% basalt, 10% yellow silt.] (A = To, B = Kd?? 270A out of place??)
290-300’	A. Very pale green and pale reddish brown mudstone, ~HCl. B. Pale gray loose sand, fine to medium grained, subround, moderately well sorted, 100% Q, muddy. Medium gray shale, +HCl. [90% sand, 10% shale]
300-310’	Very pale green and pale reddish brown mudstone, +HCl. → *Glencairn?*
310-320’	Ditto 300-310’.
320-330’	Very pale green and pale reddish brown mudstone, +HCl. White calcrete nodules (very coarse to granule). Dark gray shale, +HCl. [75% mudst., 20% calcrete, 5% shale]
330-340’	Very pale green and pale reddish brown mudstone, +HCl. Dark gray shale, +HCl. [95% mudst., 5% shale]
340-350’	Ditto 320-330’.
350-380’	No samples.
380-390’	Very pale gray silt (as a powder), +HCl.
390-400’	Ditto 380-390’.
400-410’	Very pale greenish gray mudstone, +HCl.
410-450’	No samples.
450-460’	Pale reddish brown mudstone, +HCl.
460-470’	Pale reddish brown and pale green mudstone, ~HCl.

470-480’	Ditto 460-470’.
480-490’	Very pale red mudstone, ~HCl.
490-500’	Very pale red mudstone, ~HCl. White quartz arenite, very fine grained, subround, well sorted, 100% Q, silica cemented, -HCl. [90% mudst., 10% sandst.]
500-510’	Very pale green and very pale red mudstone, +HCl. White quartz arenite, very fine grained, subround, well sorted, 100% Q, silica cemented, -HCl. [90% mudst., 10% sandst.]
510-520’	Very pale red and very pale green mudstone, ~HCl.
520-530’	Ditto 510-520’.
530-540’	Pale brownish red mudstone, well indurated, +HCl.
540-550’	Pale brownish red and very pale green mudstone, +HCl.
550-560’	Pale reddish brown and very pale green mudstone (green very minor component), +HCl. → *Jm or TrC?*
560-570’	Ditto 530-540’.
570-580’	Ditto 530-540’.
580-590’	Ditto 550-560’.
590-600’	Ditto 550-560’.
600-610’	Ditto 550-560’.
610-620’	Ditto 550-560’.
620-630’	Ditto 550-560’.
630-640’	Ditto 550-560’.
640-650’	Ditto 550-560’.
650-660’	Ditto 550-560’.

Last three bags in set unlabeled. All three contain pale green mudstone, +HCl.

Amoco Prod. #1 State EZ (22-25N-31E, TD: 2338’)

0-140’	No samples.
140-150’	Pale tan loose sand, medium to coarse grained, subangular to subround, moderately sorted, 100% Q. Very pale green and pale reddish brown mudstone, -HCl. [90% sand, 10% mudst.]
150-160’	Pale tan loose sand, very fine to medium grained, subangular to subround, moderately well sorted, 100% Q.
160-170’	Very pale green and pale reddish brown mudstone, -HCl. Minor loose quartz grains. (Washed such that mudstone fragments are very small.)
170-180’	Ditto 160-170’.
180-190’	Ditto 160-170’.
190-200’	Ditto 160-170’.
200-210’	Ditto 160-170’ plus minor component very pale gray mudstone.
210-220’	Ditto 200-210’.

220-230’	No samples.
230-240’	Very pale gray loose sand, fine to medium grained, subround, moderately well sorted, 100% Q.
240-590’	No samples.
590-600’	Very pale red mudstone, +HCl.
600-680’	Ditto 590-600’
680-690’	Reddish brown lithic arenite/wacke, medium grained, subangular, well sorted, 90% Q, 10% L (opaques), +HCl, abundant hematite cement.
690-700’	Ditto 680-690’.

Dillard State #1 (2-23N-33E, TD: 4036’)

0-10’	No samples.
10-20’	Yellow quartz wacke, fine to medium grained, subround, well sorted, 100% Q, ±15% clay matrix, -HCl. Very pale green quartz wacke, medium grained, subround, well sorted, 98% Q, 2% L (incl. red chert), patches of interstitial clay, -HCl. [50% each]
20-30’	Reddish brown siltstone, -HCl. Pale green mudstone, -HCl. Yellow quartz wacke, fine to medium grained, subround, well sorted, 100% Q, ±15% clay matrix, -HCl. [60% red silt., 20% green mudst., 20% sandst.]
30-40’	Very pale green quartz wacke, medium grained, subround, well sorted, 98% Q, 2% L (incl. red chert), patches of interstitial clay, -HCl.
40-50’	Ditto 20-30’.
50-60’	Reddish brown and very pale green siltstone, +HCl.
60-70’	Very pale green siltstone, -HCl.
70-80’	Pale green siltstone, -HCl. Reddish brown mudstone, somewhat mottled, -HCl. [70% green silt., 30% red mudst.]
80-90’	Ditto 70-80’.
90-100’	Ditto 70-80’ with single pebble of white quartz arenite, fine grained, subround, well sorted, 100% Q, with interstial clay patches, -HCl.
100-110’	Reddish brown and very pale green siltstone, -HCl. White quartz arenite/wacke, fine grained, subround, well sorted, 95% Q, % L (opaques, red chert), ±15% clay matrix in patches, -HCl. [70% silt., 30% sandst.]
110-120’	Reddish brown and very pale green siltstone, -HCl.
120-130’	Ditto 100-110’.
130-140’	Reddish brown and very pale green siltstone, -HCl. Yellow quartz wacke, fine to medium grained, subround, well sorted, 100% Q, ±15% clay matrix, -HCl. [90% silt., 10% sandst.]
140-150’	White quartz arenite/wacke, fine grained, subround, well sorted, 95% Q, % L (opaques, red chert), ±15% clay matrix in patches, pyrite locally, -HCl. Very pale green and occasionally reddish brown siltstone, -HCl. [70% sandst., 30% silt.]

150-160’	Ditto 140-150’. [95% sandst., 5% siltst.]
160-170’	Ditto 130-140’. [60% sandst., 40% siltst.]
170-180’	Ditto 130-140’.
180-190’	Ditto 130-140’.
190-200’	Ditto 160-170’.
200-210’	Very pale green and reddish brown mudstone, +HCl.
210-220’	Reddish brown and very pale green siltstone, +HCl. Yellow quartz wacke, fine to medium grained, subround, well sorted, 100% Q, ±15% clay matrix, -HCl. [80% siltst., 20% sandst.]
220-230’	Ditto 210-220’, sandstone white.
230-240’	Ditto 210-220’, sandstone white, some pyrite. → *Base of Jurassic?*
240-250’	Reddish orange and very pale green siltstone, +HCl. Reddish brown and very pale green mudstone, +HCl. White quartz arenite/wacke, fine grained, subround, well sorted, 95% Q, % L (opaques, red chert), ±15% clay matrix in patches, pyrite locally, -HCl. [50% mudst., 45% silt., 5% sandst.]
250-260’.	Ditto 240-250’.
260-270’	Ditto 240-250’.
270-280’	Ditto 240-250’.
280-290’	Ditto 240-250’.
290-300’.	Ditto 240-250’.
300-310’.	Ditto 240-250’. No sandstone.
310-320’	Ditto 240-250’.
320-330’	Ditto 240-250’.
330-340’	Reddish orange siltstone, +HCl. Reddish brown and very pale green mudstone, +HCl. [60% silt., 40% mudst.]
340-350’	Ditto 240-250’, siltstone primarily reddish orange, few pieces of green siltstone micaceous.
350-360’	Ditto 330-340’.
360-370’	Ditto 330-340’.
370-380’	Ditto 330-340’.
380-390’	Ditto 330-340’.
390-400’	Reddish orange siltstone, ~HCl. Reddish brown mudstone, ~HCl. [60% siltst., 40% mudst.]
400-410’	Ditto 330-340’.
410-420’	Ditto 330-340’.
420-430’	Ditto 330-340’. [60% mudst., 40% siltst.]
430-440’	Ditto 420-430’.
440-450’	Ditto 330-340’.
450-460’	Ditto 330-340’.
460-470’	Ditto 420-430’.

470-480’	Ditto 330-340’
480-490’	Ditto 420-430’.
490-500’	Ditto 330-340’.
500-510’	Ditto 420-430’.
510-520’	Ditto 330-340’.
520-530’	Ditto 420-430’.
530-540’	Ditto 420-430’.
540-550’	Ditto 420-430’.
550-560’	Ditto 420-430’.
560-570’	Ditto 420-430’.
570-580’	Ditto 420-430’.
580-590’	Ditto 420-430’.
590-600’	Ditto 420-430’. [70% mudst., 30% siltst.]
600-610’	Reddish brown mudstone, somewhat mottled, -HCl.
610-620’	Ditto 420-430’.
620-630’	Reddish orange mudstone, somewhat mottled, ~HCl.
630-640’	Ditto 600-610’.
640-650’	Ditto 600-610’, but +HCl. Includes small calcrete nodule.
650-660’	Reddish brown mudstone, ~HCl. Very pale gray mudstone, ~HCl. [50% each]
660-670’	Orangish red and pale green mudstone, ~HCl.
670-680’	Ditto 620-630’.
680-690’	Ditto 620-630’.
690-700’	Ditto 620-630’.

Olson #1 Zurick (2-21N-34E, TD: 2925’)

0-230’	No samples.
230-240’	Pale red mudstone, some mottling, +HCl.
240-250’	Pale red siltstone, some mottling, -HCl.
250-260’	Pale red mudstone, mottling more prominent, +HCl.
260-270’	Reddish orange siltstone, -HCl.
270-280’	Reddish orange siltstone, some mottling, +HCl. Brownish red mudstone, with mottling, +HCl. [80% siltst., 20% mudst.]
280-290’	Reddish orange siltstone, some mottling, +HCl. Very pale orange siltstone to quartz wacke, very fine grained, rounded, well sorted, 100% Q, >15% clay matrix, +HCl. [70% orange, 30% white]
290-300’	Ditto 280-290’. [90% orange, 10% white]
300-310’	Reddish orange siltstone, some mottling, +HCl.
310-320’	Ditto 300-310’.
320-330’	Ditto 300-310’.

330-340’	Pale purple mudstone, +HCl. Reddish orange and very pale orange siltstone, +HCl. [70% siltst., 30% mudst.]
340-350’	Reddish orange siltstone, some mottling, +HCl.
350-360’	Reddish orange loose sand, very fine grained, rounded, well sorted, 100% Q, somewhat muddy. → *Je?*
360-370’	Reddish orange siltstone, some mottling, +HCl. Brownish red mudstone, with mottling, +HCl. [80% siltst., 20% mudst.]
370-380’	Reddish orange loose sand, very fine to silt, rounded, well sorted, 100% Q, muddy. Very pale gray siltstone, very well indurated, +HCl. [80% loose silt, 20% white siltst.]
380-390’	Very pale red siltstone, +HCl.
390-400’	Ditto 350-360’.
400-410’	Reddish orange loose silt, rounded, well sorted, 100% Q, muddy. Very pale gray siltstone, very well indurated, +HCl. Brownish red mudstone, with mottling, +HCl. [90% loose silt, 6% white siltst., 4% mudst.]
410-420’	Reddish orange mudstone, some mottling, +HCl.
420-430’	Pale red mudstone, +HCl.
430-440’	Pale red mudstone, some mottling, +HCl.
440-450’	Reddish purple mudstone, some mottling, +HCl.
450-460’	Reddish orange and white siltstone, mostly as loose silt, +HCl.
460-470’	Pale red mudstone, +HCl.
470-480’	Brownish red mudstone, +HCl.
480-490’	Brownish red mudstone, +HCl.
490-500’	Brownish red mudstone, +HCl.
500-510’	Reddish orange and white siltstone, mostly as loose silt, +HCl.
510-515’	Ditto 500-510’.
515-525’	Pale brown loose sand, fine grained, subangular, well sorted, 85% Q, 15% L (incl. green clay, opaques, muscovite).
525-530’	Pale brown loose sand, fine grained, subangular, well sorted, 85% Q, 15% L (incl. green clay, opaques, muscovite). Reddish orange and white siltstone, +HCl. [90% sand, 10% siltst.]
530-535’	No samples.
535-545’	Very pale green sandy siltstone. Sand grains fine to medium, subrounded, moderately well sorted, 100% Q. +HCl.
545-555’	Pale brown loose sand, fine grained, subangular, well sorted, 85% Q, 15% L (incl. green clay, opaques, muscovite).
555-565’	Pale brown loose sand, fine grained, subangular, well sorted, 85% Q, 15% L (incl. green clay, opaques, muscovite). Reddish orange and white siltstone, +HCl. [90% sand, 10% siltst.]

565-575’	Pale green mudstone with very coarse grains of micrite and quartz. Some pyrite. –HCl.
575-585’	Pale brown loose sand, fine grained, subangular, well sorted, 85% Q, 15% L (incl. green clay, opaques, muscovite). Reddish orange and white siltstone, +HCl. [70% sand, 30% siltst.]
585-595’	Pale green mudstone with very coarse grains of micrite and green clay rip-ups. Some pyrite. +HCl.
595-605’	Pale brown loose sand, fine grained, subangular, well sorted, 85% Q, 15% L (incl. green clay, opaques, muscovite). Some pyrite.
605-615’	Pale brown loose silt. Some muscovite.
620-625’	Pale brown loose sand, very fine to fine grained, subangular, well sorted, 85% Q, 15% L (incl. green clay, opaques, muscovite).
625-635’	Reddish brown mudstone. Some granules of micrite. +HCl.
635-645’	Ditto 625-635’.
645-655’	Reddish brown and very pale green mudstone, -HCl.
655-665’	No samples.
665-675’	Reddish orange siltstone, some micrite granules, +HCl.
675-685’	Reddish brown mudstone. Some granules of micrite. -HCl.
685-695’	Ditto 675-685’.
695-705’	Ditto 675-685’.