New Mexico Bureau of Mines and Mineral Resources

Open-File Report 213

PRELIMINARY ESTIMATES OF RECHARGE AT THE NAVAJO MINE BASED ON CHLORIDE IN THE UNSATURATED ZONE

by

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CONTENTS

Appendices

Figures

Tables

INTRODUCTION

Problem and Purpose

The Navajo coal mine, operated by Utah International, Incorporated, is located on the Navajo Indian Reservation, approximately 12 mi west and 5 mi south of the city of Farmington, San Juan County, New Mexico (Figure 1). Ground-water recharge is an important factor in assessing hydrologic impact of mining, because it is a major component of the water budget of a mine area. However, recharge data have not been available for the Navajo mine. The purpose of this study, therefore, was to determine rates and controls of recharge in various landscape settings typical of the mine area.

Regional Setting

The mine lies in the northwestern part of the structural feature known as the San Juan Basin, a Laramide (Late Cretaceous-Early Tertiary) depression at the eastern edge of the Colorado Plateau. More specifically, it is situated just east of the Hogback Mountain Monocline which separates the Four Corners platform from the central San Juan Basin.

Coal is strip-mined from the Fruitland Formation (Cretaceous) which lies at the surface in this area. The Fruitland is generally 200-300 ft thick and consists of inter-bedded sandy shale, carbonaceous shale, clayey sandstone, coal and sandstone (Stone and others, 1983).

Data collected at the mine (Utah International, Incorporated, 1981) indicate the climate is arid with an average annual rainfall of 5.7 inches, based on the period 1962-1980.

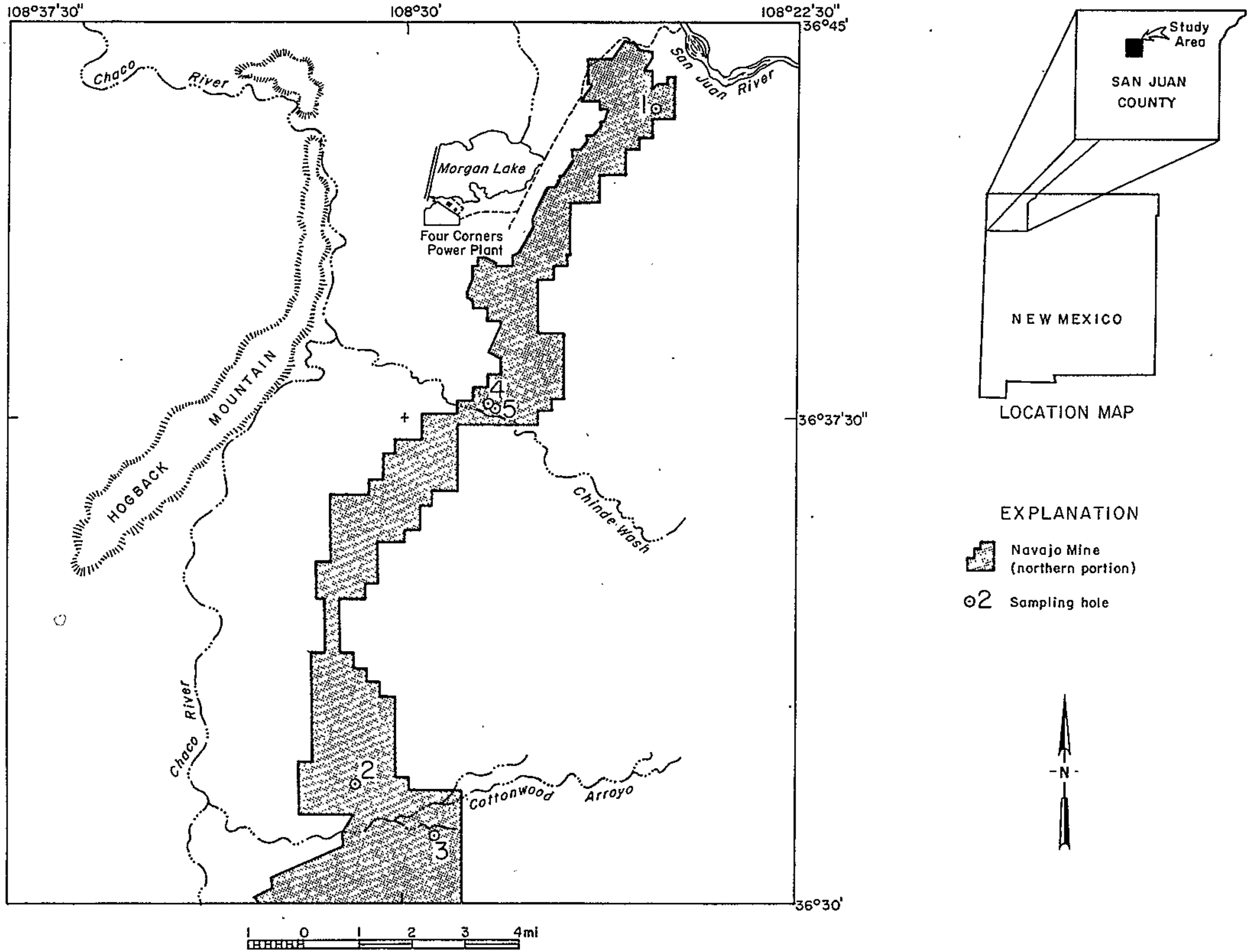

Figure 1. Location of Navajo Mine and sampling holes

Greatest precipitation occurs in the months of August through October. Average annual class-A pan-evaporation rate is 55.9 inches or nearly 10 times the rainfall.

According to a map by the Soil Conservation Service, soils are light-colored, cool, desertic types (U.S. Bureau of Reclamation, 1976). The area lies in the upper Sonoran life zone (Bailey, 1913) and vegetation would generally be classified as grassland with yuccas and cacti (U.S. Bureau of Reclamation, 1976).

The area studied near Yazzie Ramp 1 (Holes 4 and 5) was reclaimed during 1978 and 1979. At that time the total amount of water added through irrigation was 6 inches. The seed mix applied for revegetation was Atriplex. This mix includes alkali sacaton, galleta, globe mallow, Indian rice grass, and sand dropseed. The average rooting depth is probably < 2 ft.

The mine area is drained by the San Juan River and it's tributaries. The San Juan is perennial, but the tributaries are ephemeral. The streams associated with sampling sites include Cottonwood Arroyo in the south, Chinde Wash in the middle of the study area, and an unnamed stream in the north. Cottonwood Arroyo and Chinde Wash flow west into Chaco River and the unnamed stream in the north flows north into the San Juan River just east of the Nenahnezad Indian School (Figure 1).

APPROACH AND METHODS

Determining Recharge

Recharge may be determined by various methods, employing either chemical or physical parameters. Chemical methods deduce flux mainly from the concentration of selected natural isotopes in interstitial water of the unsaturated zone (vadose water). Isotopes which have been used include carbon 14 (Mook, 1980), chloride (Allison and Hughes, 1978), chlorine 36 (Phillips and others, 1984), oxygen 18 and deuterium (Barnes and Allison, 1983), and tritium (Smith and others, 1970). Additionally, chemical tracers and dyes may be introduced to determine water movement in the vadose zone (Freeze and Cherry, 1979). Physical methods measure or derive recharge from various physical conditions in the unsaturated or saturated zone. The shape of the water table and aquifer properties have been used by Theis (1937) and Ferris and others (1962). The water budget may also be used. Input (precipitation, irrigation, leakage from underlying aquifers, runon of surface water) equals output (surface loss due to runoff and evapotranspiration, subsurface loss due to ground-water recharge). Data are usually readily obtainable for all components except evapotranspiration and recharge. Methods of estimating evapotranspiration have been limited to croplands (Blaney and Hanson, 1965). Recharge may also be determined from infiltration, neutron-probe, and soil-physics studies (Klemt, 1981; Freeze and Banner, 1970; Sophocleous and Perry, 1984).

Chloride Method

In the Navajo Mine study, recharge was estimated from the amount of chloride in vadose water. This method was chosen for several reasons. First, it is simpler than other chemical methods, requiring only ordinary laboratory equipment. Because the chloride method is relatively simple, analyses are cheaper than those for other isotope methods. In view of the large number of samples involved, approximately 250, the cost of other methods was prohibitive. Physical methods based on neutron-probe studies or in-situ soil physics instrumentation are also more expensive. Physical methods based on the shape of the water table and aquifer properties are not appropriate because the aquifer is generally fractured coal rather than material with mainly intergranular porosity.

In the chloride method, recharge is determined from the relationship $R = Clp/Clsw \cdot P$, where R = recharge (inches/yr), Clp = average chloride concentration in local precipitation (mg/L), Clsw = average chloride concentration (mg/L) in the soil water, and P = average annual precipitation (inches/yr). Clp and P are either measured or obtained from the literature. Clsw is determined from plots of analytical results. Recharge is inversely proportional to Clsw; the higher the Clsw, the lower the recharge and <u>vice versa</u>.

Although Clp is not known for the Navajo mine, data are available for stations at Socorro, New Mexico, to the south, and Grand Junction, Colorado, to the north. Clp at Socorro is 0.33 mg/L (Fred Phillips, Geoscience Department, New Mexico Tech, personal communication, July 1984) and that at Grand Junction is 0.86 mg/L (Lodge and others, 1968). Precipitation at the two stations is the same, approximately 10 inches. Because these Clp values are of the same order of magnitude, recharge calculations based on them are of the same order of magnitude, regardless of which Clp is used. Nonetheless, it was decided that an average of the two available values, 0.60, be used as Clp in the preliminary Navajo mine recharge calculations.

Samples of precipitation at the Navajo Mine are now being collected and analyzed so that a local value for Clp may be determined. The three samples received to date gave chloride readings two orders of magnitude higher than the Grand Junction and Socorro values. For a 0.04-inch event on 31 August/1 September, chloride was 18.7 mg/L; for a 0.08-inch event on 26 September, chloride was 9.9 mg/L; and for a 0.14-inch event, 1-4 October, chloride was 10.2 mg/L. These chloride contents are higher than regional values would suggest because of 1) power-plant emissions in the area (chloride naturally occurring in coal is released upon combustion) and 2) collection of saline dust in the rain gage. Coal may contain on the order of a few hundred ppm of chloride (National Research Council, 1980). Little of this is water soluble so it stays with the coal until it is released to the atmosphere during combustion. The addition of dust to the rain samples is not undesirable inasmuch as dust is also added to the land surface where soil samples are taken and thus provides a measure of an additional natural source of chloride input.

Because the total annual chloride input at Navajo Mine (precipitation plus dust) is not yet known, the specific effect of the higher Clp on recharge estimates cannot be determined. In general, however, an increase in Clp has the effect of increasing recharge. A 100-fold increase in Clp could cause a 10-fold increase in recharge. For example, for a Clsw of 400 mg/L and a P of 5.7 inches, recharge would be 0.01 inch/yr using a Clp of 0.60 mg/L and 0.86 inch/yr if Clp is 60 mg/L. The recharge rates reported herein are based on an average regional Clp value rather than an on-site measurement. Because of the indicated antiquity of the soil water sampled, these values are probably reasonable. Total chloride entering the soil at that time may have been higher than allowed because of contributions from dust. However, Clp could not have been as high as suggested by modern precipitation samples.

P for the Navajo mine is 5.7 inches (Utah International, Inc., 1981).

Clsw varies from site to site and is the only part of the recharge equation that changes. Clsw is determined from chloride vs depth profiles. The median value or arithmetic mean may be used. The median emphasizes the extremes; the mean represents all measurements.

In the chloride method, it is assumed that 1) recharge occurs only by piston flow, 2) precipitation is the sole source of chloride entering the ground, 3) precipitation has been constant through the time represented by the samples, and 4) chloride content of precipitation has also been constant during this time. These assumptions are not always valid. For example, some recharge by non-piston flow may occur along fractures or root channels. The chloride in precipitation, originating from salt particles formed by the evaporation of sea water, dust from dry saline lake beds, and industrial emissions, may not be the only source of chloride entering the soil. Chloride may also be added directly through dryfall of saline dust or fertilizer, in the case of croplands. In rare cases some chloride may even be derived from the rock or soil material themselves; the method is usually not applied where this is suspected. Average annual precipitation has no doubt varied through time. Of particular interest is the fact that the Pleistocene climate was wetter than that of the present. Chloride content of precipitation is related to distance from the ocean (Hutton, 1976). Lower sea levels in the Pleistocene would have resulted in increased distance from the coast and thus lower chloride concentrations in precipitations at that time.

In view of these deviations from the assumptions, results of the chloride method are considered estimates of recharge. However, values obtained by this method compare favorably with results of more complex and expensive methods. A plot of recharge determined from chloride vs that from the tritium data gave a straight line for a study in Australia (Allison and Hughes, 1978). In comparing results of the chloride and tritium methods, they noted that chloride should give the best estimates of recharge in arid regions. Tritium data also corroborated recharge estimates from chloride in another study in Australia (Allison and others, in press). Rates of recharge to the

Ogallala Formation in Curry County, New Mexico, based on the chloride method, are compatible with those determined in adjacent areas of New Mexico and Texas from neutron-probe data and physical characteristics of the water table and aquifer (Stone, 1984).

Sampling

Recharge was determined at five landscape settings typical of the mine property: valley bottom, upland flat, badlands, depression in reclaimed area,, flat in reclaimed area (Table 1). Such settings represent the main combinations of geology, slope, vegetation, and land-use history found at the Navajo mine. Examples of these settings from throughout the mine area were selected for sampling (Figure 1).

Samples of the unsaturated zone were obtained by means of a CME-55 hollow-stem-auger rig, under contract with Fox and Associates of New Mexico, Incorporated, Albuquerque. Holes were cored continuously, 5 ft at a time using a 5-ft split core barrel (CME's 6" OD continuous sample tube system). Recovery was generally 100% except in the upper 5-15 ft where it ranged from 0 (rare) to 80%. The resulting core was ~ 2 1/4 inches in diameter.

Drilling was done without air, mud, or water circulation in order to preserve natural soil-moisture content in the samples. However, water was occasionally added to reduce intense friction caused by the presence of sticky claystones in the upper part of some holes. In such cases water was poured down the outside of the auger string. Approximately 5 gal was added for every 10 ft of drilling (2 auger flights). Total water thus added never

Table 1. Source of Samples

Hole	Setting	Location	Total Depth (ft)	Interval Sampled (ft)
1	Valley Bottom	Bitsui Area	75	0-75
2a	Upland Flat	Area III	25	0-25
2b	Upland Flat [1]	Area III	39	30-39
3a	Badlands	Cottonwood Arroyo	25	0-25
3b	Badlands [1]	Cottonwood Arroyo	68	25-68
4	Reclaimed Depression	Yazzie Ramp 1	74	0-74
5	Reclaimed Flat	Yazzie Ramp 1	61	0-61

[1] offset from Hole 2a 350 ft to the east

[2] offset from Hole 3a 125 ft to the north

exceeded ten gallons. Such water was never observed to have reached the core barrel.

A single sample, placed in a 1-oz covered plastic jar and sealed with plastic electrical tape, served for both soil-moisture and chloride determinations. Such samples were taken at approximately 0.5-ft intervals in the upper 5 ft and at 1-ft intervals below that. Where recovery was less than 100%, a convention was adopted of assigning the material obtained to the upper part of the depth interval represented. For example, if only 3 ft were recovered from a depth of 4-9 ft, it was assumed to represent the interval 4-7 ft.

Analysis

Recharge determination by the chloride method involves several steps (Figure 2). First, soil moisture is determined gravimetrically. The oven-dried sample is then shaken mechanically for 6 hours with a known amount of deionized water to remove salt originally dissolved in the soil water. Next, the chloride content of this extract is determined by means of either a specific-ion electrode or mercuric-nitrate titration, if the concentration is below the detection limit of the electrode (1.85 mg/L). The chloride concentration of the original soil water is then calculated with a computer program (CHLORE.FOR), based on the chloride content of the extract, the soil-moisture content, the amount of dry sample used, and the amount of deionized water added (Appendix B).

Resulting chloride values are plotted against depth on arithmetic graph paper. The profiles produced typically show an

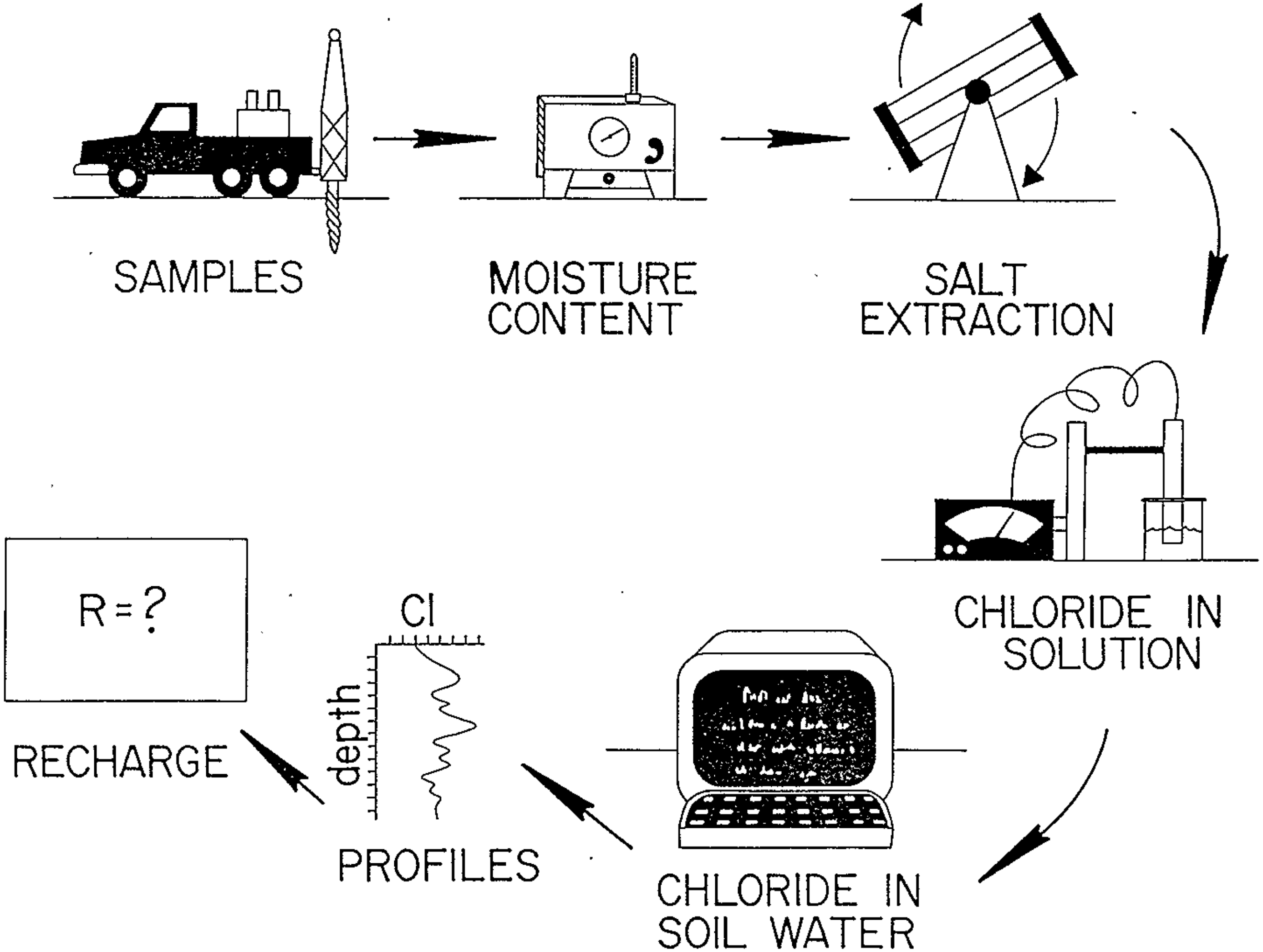

Figure 2. Flow diagram for chloride method.

increase in the chloride content through the root zone to a maximum value, that is more or less maintained to the water table. The chloride content of the root zone is not in equilibrium so the average chloride value below the peak is what is used as Clsw to estimate recharge in an undisturbed area. In areas where land-use has been modified, the pre-modification rate is based on the average chloride content of the lower part of the profile, whereas, current or post-modification recharge is based on the average chloride content of the upper part of the profile (but below the root zone). Average chloride contents used to determine recharge in this study are given in Table 2. Similar recharge rates were obtained regardless of whether the median or mean chloride value was used (Table 3).

In profiles where the chloride content decreases with depth below the peak, one of two conditions may be assumed. Either fresh water is reaching the lower part of the profile by other than piston flow, or conditions at the site were more favorable for recharge at the time represented by the lower part of the profile. In the case of non-piston flow, fresh water moves rapidly downward along fractures, roots, animal burrows, or other highly conductive features. If this is not the case, precipitation, chloride input, and/or recharge can be assumed to have changed with time (Allison and others, in press).

Plots of cumulative chloride content (g/m^2) vs cumulative water content (m) on arithmetic graph paper help identify periods of change at sites where the chloride content decreases markedly with depth. Cumulative chloride is obtained as follows:

$\sum_{1}^{i} (\Theta vi \cdot Clswi) \cdot di$, where Θvi = volumetric water

Table 2. Determination of Soil-water Chloride (Clsw) From Chloride *vs* Depth Plots

Hole	Setting	Cl min (mg/L)	Cl max (mg/L)	Range (mg/L)	Clsw[2] (mg/L)	Clsw[3] (mg/L)
1	Valley Bottom	688.06	2099.09	1411.03	1394	1454
2	Upland Flat	56.94	424.36	367.42	241	163
3	Badlands	137.39	737.31	599.92	437	322
4	Reclaimed Depression[1]	59.07 167.44	363.63 865.40	304.56 697.96	211 516	109 418
5	Reclaimed Flat[1]	52.72 175.41	359.42 702.45	306.70 527.04	206 439	128 416

[1] top value represents upper segment of profile; bottom value represents lower segment of profile

[2] median chloride value; $= \frac{\text{Range}}{2} + \text{Cl min}$; rounded off to nearest whole number for recharge calculations

[3] mean chloride value; = arithmetic average of values in same depth interval over which median value determined

Table 3. Recharge Determinations, Chloride *vs* Depth Plots

Hole	Setting	R median[2] (inches/yr)	R mean[3] (inches/yr)
1	Valley Bottom	0.002	0.002
2	Upland Flat	0.02	0.02
3	Badlands	0.01	0.01
4	Reclaimed Depression	0.02[4]	0.03[4]
		0.01[3]	0.01[5]
5	Reclaimed Flat	0.02[4]	0.03[4]
		0.01[5]	0.01[5]

[1] based on $R = \frac{Clp}{Clsw} \cdot P$, where Clp = 0.60 mg/L, Clsw as in Table 2, and P = 5.7 inches/yr

[2] recharge based on median Clsw values (Table 2)

[3] recharge based on mean Clsw values (Table 2)

[4] = post-reclamation recharge (using clsw from upper part of Cl *vs* depth profile)

[5] = pre-reclamation recharge (using Clsw from lower part of Cl *vs* depth profile)

content (m^3/m^3) at depth i, and di = sample interval length at depth i (Appendix B); similarly, cumulative water content is the $\sum_i (\Theta vi \cdot di)$.

Such plots should give a straight line if there has been no change in precipitation, chloride input, and/or recharge. If there has been a change in any of these conditions, the plots result in curved lines. These curves are often characterized by straight-line segments, representing periods of fairly constant conditions. The age of the end points of such segments may be estimated from the relationship A = Clsw/Clp • P, where A = age (yrs), Clsw = cumulative chloride content (g/m^2) per unit of soil in the unsaturated zone at that point, Clp = modern chloride content (g/m^3) of precipitation, and P = modern average annual precipitation (m/yr). Additionally, recharge rates for each segment of the cumulative chloride *vs* cumulative water plot may be estimated as for the chloride *vs* depth plots, using the modern chloride content of precipitation (mg/L), the average chloride content (mg/L) of the soil water in the samples corresponding to the segment, and modern precipitation (inches/yr).

RESULTS

Hole 1: Undisturbed Valley Bottom (Bitsui area)

This site was selected so as to learn recharge in a natural valley not filled with alluvium. Such a setting is presumably subject to occasional flooding from the adjacent channel and/or to runon from the adjacent slope.

Samples for this setting were obtained near an unnamed natural channel in the Bitsui area. The hole penetrated 75 ft of mainly Fruitland Formation (Appendix A). There was no recovery from the first core as adjustments were necessary to change the equipment to vertical drilling from slant-hole drilling on the previous job. Thus, the thickness of alluvium was not documented. Based on field observations, however, it is probably less than 1 ft thick at this site.

Water table was not reached in this hole, but a water level is available for a nearby well. At Utah International's well no. KF8416, approximately 3 miles due east of Hole 1, depth to water is 145 ft.

Soil moisture fluctuates considerably between 0.02 and 0.16 g/g. The median is approximately 0.07 g/g (Figure 3).

The chloride vs depth profile here differs from all others obtained in two problematical ways. First, the chloride values are considerably higher than at other sites. The maximum value is 3818.93 mg/L and the Clsw (median value) below the peak is 1394 mg/L. Second, the chloride peak is quite deep: 36 ft. The reason for these observations is uncertain. Perhaps they represent a time of higher ground-water level, prior to the

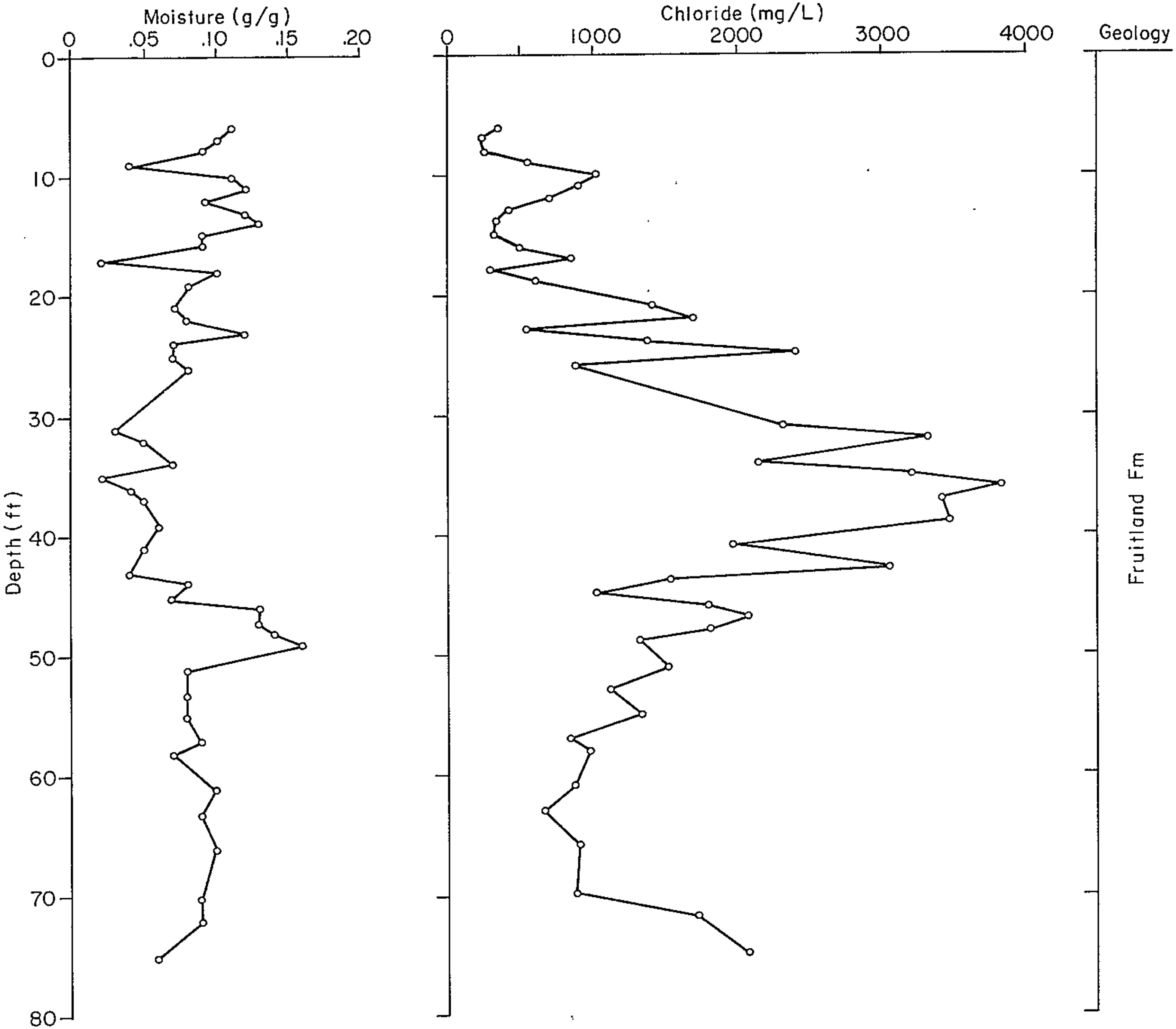

Figure 3. Results from Hole I, valley bottom.

twisted the core barrel beyond repair. A total of 39 ft was sampled at Hole 2. Recovery was poor in the alluvium, but it is probably less than 5 ft thick; the rest of the samples are from the Fruitland Formation (Appendix A).

Water table was not encountered in either Hole 2a or 2b. Shallowest ground-water in this area would be that associated with the first coal seam (no. 8). At a nearby well (Utah International's no. KF10), this coal is 179 ft deep.

Moisture fluctuates between approximately 0.1 and 0.3 g/g above 20 ft but levels off to approximately 0.1 g/g below that (Figure 4). The bulge at approximately 15 ft corresponds to a carbonaceous shale which may have a relatively higher water-holding capacity than associated rock types.

Median chloride content reaches a maximum of 1595.52 mg/L at a depth of 0.75 ft. Below that the median Clsw is 241 mg/L (Figure 4).

Recharge at this site is determined to be 0.02 inch/yr. This is the highest rate of any undisturbed site (Table 3). Occasional runon due to the slope at this site, and the presence of blow sand at the surface are responsible.

The chloride <u>vs</u> depth profile for Hole 2 differs from that for other holes in that chloride content decreases below the peak. This suggests that either non-piston-flow recharge has occurred below the peak or recharge at the site was greater at the time represented by the lower part of the profile. Because low chloride values occur throughout the lower portion of the plot, non-piston-flow is unlikely. Thus a higher recharge in the past is indicated.

cutting of this valley.

Recharge determined at this site, 0.0002 inch/yr, is an order of magnitude less than at all other sites (Table 3). Such a value is based on the interval below the chloride peak. Chloride content above this seems to be lower and more comparable to that at the other badlands site (Hole 3). However, that portion of the profile does not appear to be in equilibrium and no recharge estimate should be attempted. Flooding and/or runon may be responsible for the lower chloride values above the peak (Figure 3).

Hole 2: Upland Flat (Area III)

This site was selected in order to learn recharge in an undisturbed upland area. Ideally, such a setting would receive minimum recharge because there would be no flooding or runon and because there is no spoil at the surface to enhance infiltration. In fact, however, there is a gradual slope toward the southwest so some runon may occur in severe storms.

Samples for this setting were obtained from 2 holes in the undissected upland surface, north of Cottonwood Arroyo. The first hole (2a) penetrated only 25 ft before reaching auger refusal. After drilling the other three project holes, the rig was relocated approximately 350 ft to the east of the first hole and a second hole (2b) was drilled without sampling to a similar depth to see if the hard zone was present there as well. It was not encountered to a depth of 29 ft, so sampling was resumed at 30 ft. At a depth of 44 ft another hard zone stripped the bit off, unraveled the flange on the lowermost auger flight, and twisted the core barrel beyond repair. A total of 39 ft was sampled at Hole 2. Recovery was poor in the alluvium, but it is probably less than 5 ft thick; the rest of the samples are from the Fruitland Formation (Appendix A).

Water table was not encountered in either Hole 2a or 2b. Shallowest ground-water in this area would be that associated with the first coal seam (no. 8). At a nearby well (Utah International's no. KF10), this coal is 179 ft deep.

Moisture fluctuates between approximately 0.1 and 0.3 g/g above 20 ft but levels off to approximately 0.1 g/g below that (Figure 4). The bulge at approximately 15 ft corresponds to a carbonaceous shale which may have a relatively higher water-holding capacity than associated rock types.

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Recharge at this site is determined to be 0.02 inch/yr. This is the highest rate of any undisturbed site (Table 3). Occasional runon due to the slope at this site, and the presence of blow sand at the surface are responsible.

The chloride vs depth profile for Hole 2 differs from that for other holes in that chloride content decreases below the peak. This suggests that either non-piston-flow recharge has occurred below the peak or recharge at the site was greater at the time represented by the lower part of the profile. Because low chloride values occur throughout the lower portion of the plot, non-piston-flow is unlikely. Thus a higher recharge in the past is indicated.

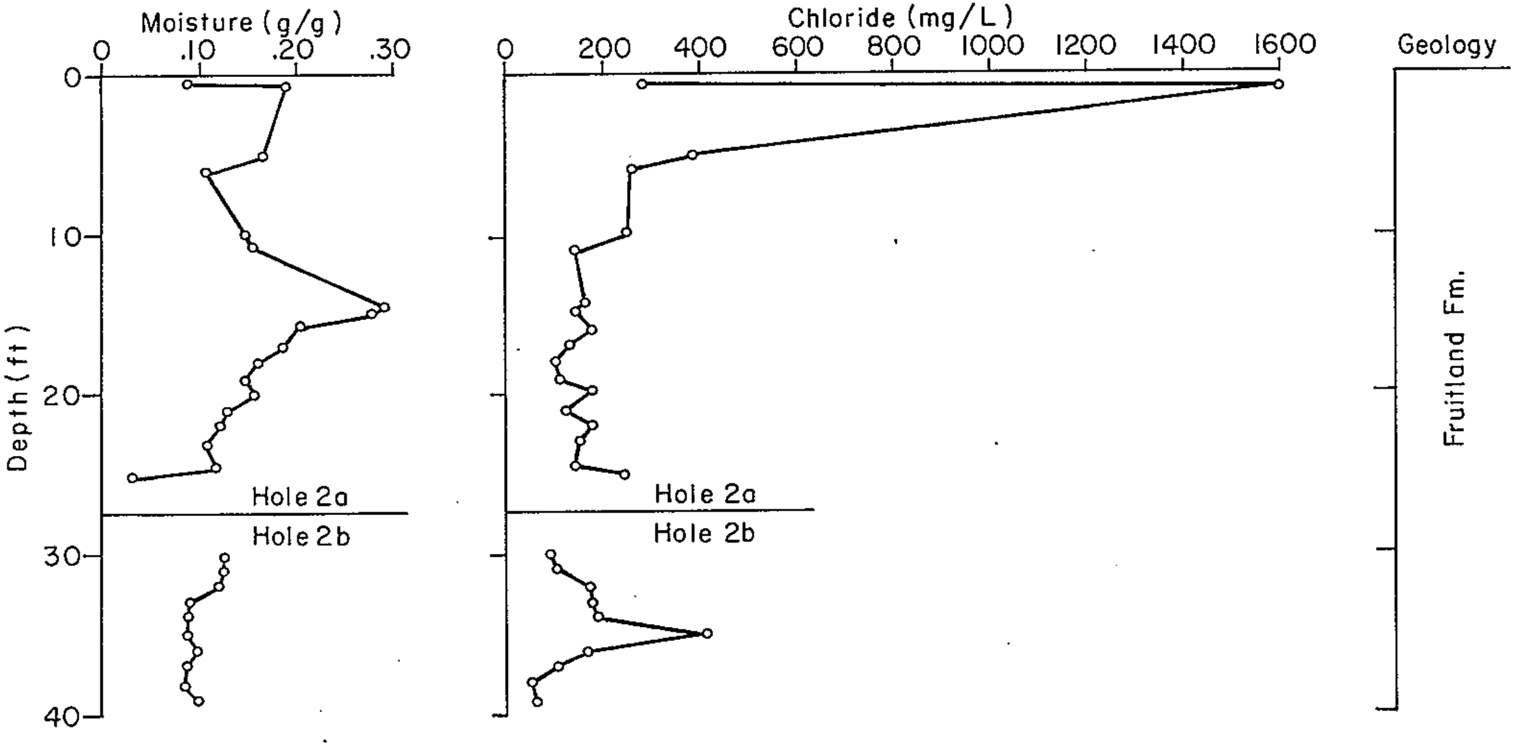

Figure 4. Results from Hole 2, upland flat.

A cumulative chloride *vs* cumulative water plot (Figure 5) shows that recharge rate has indeed decreased through time. Soil-water chloride values, ages, and recharge rates associated with various straight-line segments of this plot are given in Tables 4 and 5. Soil water at the bottom of the hole (39 ft) is 7,914 yrs old. Between 7,914 and 7,745 yrs BP, recharge is calculated to have been 0.0142 inch/yr. In the period 7,745 - 7,081 yrs BP, recharge was 0.0134 inch/yr. From 7,081 to 5,120 yrs BP, recharge was fairly constant at 0.0189 inch/yr. Between 5,120 urs ago and 4,301 yrs ago, recharge was 0.0113 inch/yr. Such calculations for shallow depth (in the root zone) are generally unreliable so were not attempted.

The changes in recharge rate documented in Figure 5 are in general agreement with paleoclimate reconstructions made for the Chaco Canyon area from packrat-midden data by Betancourt and others (1983). They found that the late summer monsoonal rainfall pattern had developed by 8,300 yrs ago and that effective moisture was greater than today in the period between 7,500 and 4,000 yrs BP.

Hole 3: Badlands (Cottonwood Arroyo)

This site was chosen to represent outcrop areas of the Fruitland Formation. Recharge in such settings should be low, owing to high runoff and the tightness of the strata.

Samples for this setting were obtained from 2 holes adjacent to Utah International's piezometer nest Kf84-21. As in drilling Hole 2, a hard zone was encountered at 25 ft, so drilling was continued in an offset hole (3b) located approximately 125 ft

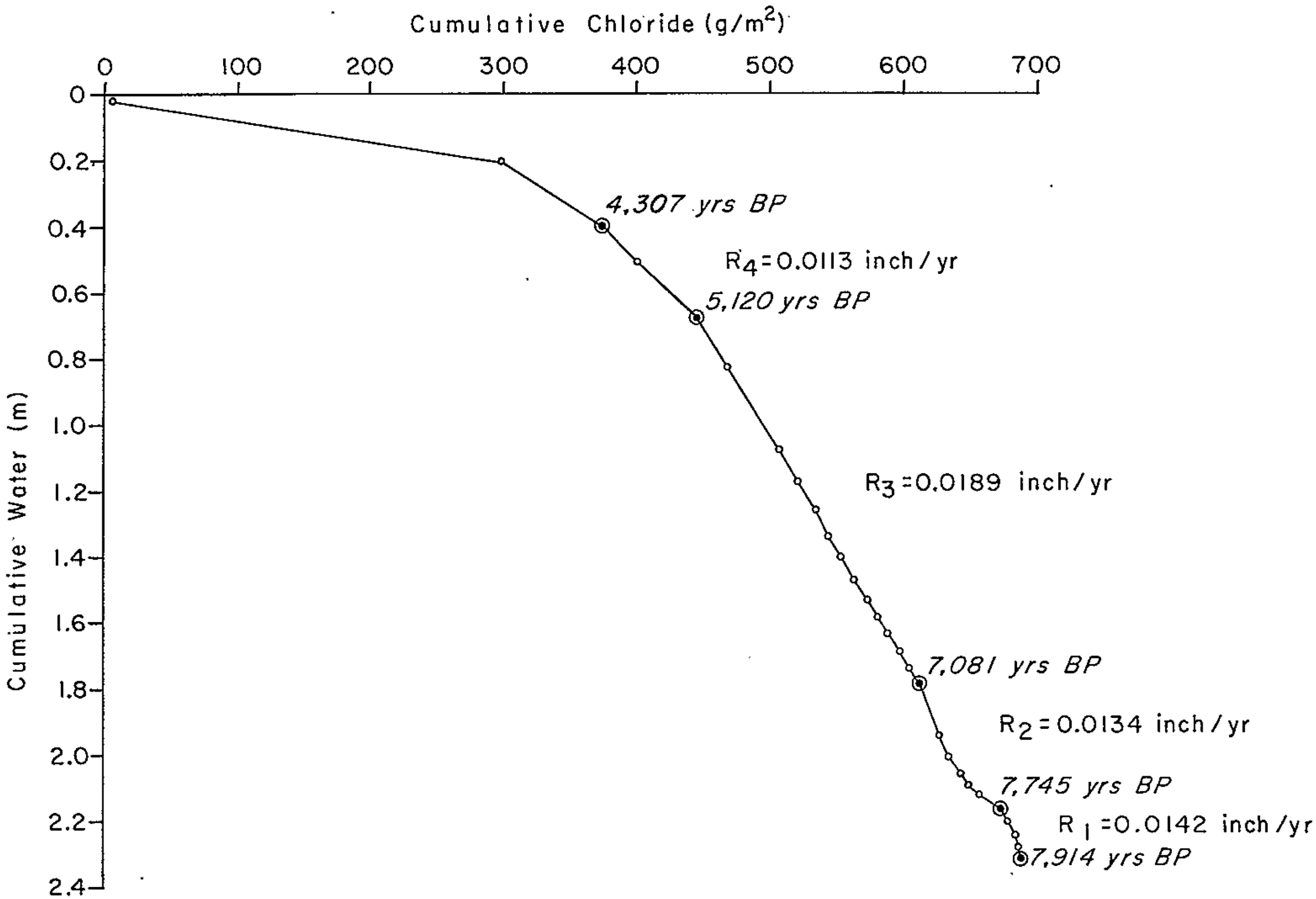

Figure 5. Choride vs Water, Hole 2 (upland flat)

Table 4. Determination of Soil-water Chloride (Clsw) From Cumulative Chloride *vs* Cumulative Water Plot For Hole 2

Segment	Cl min (mg/L)	Cl max (mg/L)	Range (mg/L)	Clsw[1] (mg/L)
R4	252.94	350.92	97.98	301.93
R3	108.37	252.94	144.57	180.65
R2	85.45	242.27	156.82	163.86
R1	56.94	424.36	367.42	240.65

[1] median chloride value; = Range/2 + Cl min

Table 5. Recharge Determinations From Cumulative chloride *vs* cumulative water plot, Hole 2

Segment	Depth (ft)	Age (yrs BP)	Recharge[1] (inch/yr)
R4	10 - 5	5120 - 4307	0.0113
R3	25 - 10	7081 - 5120	0.0189
R2	35 - 25	7745 - 7081	0.0134
R1	39 - 35	7914 - 7745	0.0142

[1] based on $R = \frac{Clp}{Clsw} \cdot P$, where Clp = 0.60 mg/L, Clsw as in Table 4, and P = 5.7 inches/yr

north of the first hole (3a). Drilling without sampling to 25 ft in the second hole did not encounter the hard zone and sampling was resumed until auger refusal at 68 ft. A total of 68 ft (all Fruitland Formation) was sampled at Hole 3 (Appendix A).

Water table was deeper than either Hole 3a or 3b. However, Utah International's Hole KF8422, at this site, reached the highest saturated zone (coal no. 8) at a depth of 118 ft.

Moisture is more uniform at this setting, ranging from 0.04 to 0.13 g/g. The median value is 0.085 g/g (Figure 6).

Chloride content increases to a peak of 736.10 mg/L at a depth of 0.5 ft, then drops off rapidly below that (Figure 6). Chloride increases again below approximately 40 ft. The median value of Clsw is 437 mg/L (Table 2).

Recharge for this setting is calculated to be 0.01 inch/yr. This is the second lowest value determined in the study (Table 3).

Hole 4: Reclaimed Area - Depression (Yazzie Area)

This setting was chosen in order to learn the effects on recharge of depressions, where water periodically ponds. In other studies recharge has been found to be greater in depressions caused by dissolution/collapse (sinkholes; Allison and others, in press) and deflation (playas; Stone, 1984). Additionally, effects of reclamation should be discernible here.

Samples for this setting were obtained from a hole near Yazzie Ramp No. 1. A total of 74 ft was penetrated in Hole 4. The uppermost 25 ft were spoil, the next 22 ft were alluvium, and the bottom 26 ft were Fruitland Formation Appendix A). The last 5 ft of samples were very wet and probably came from below the

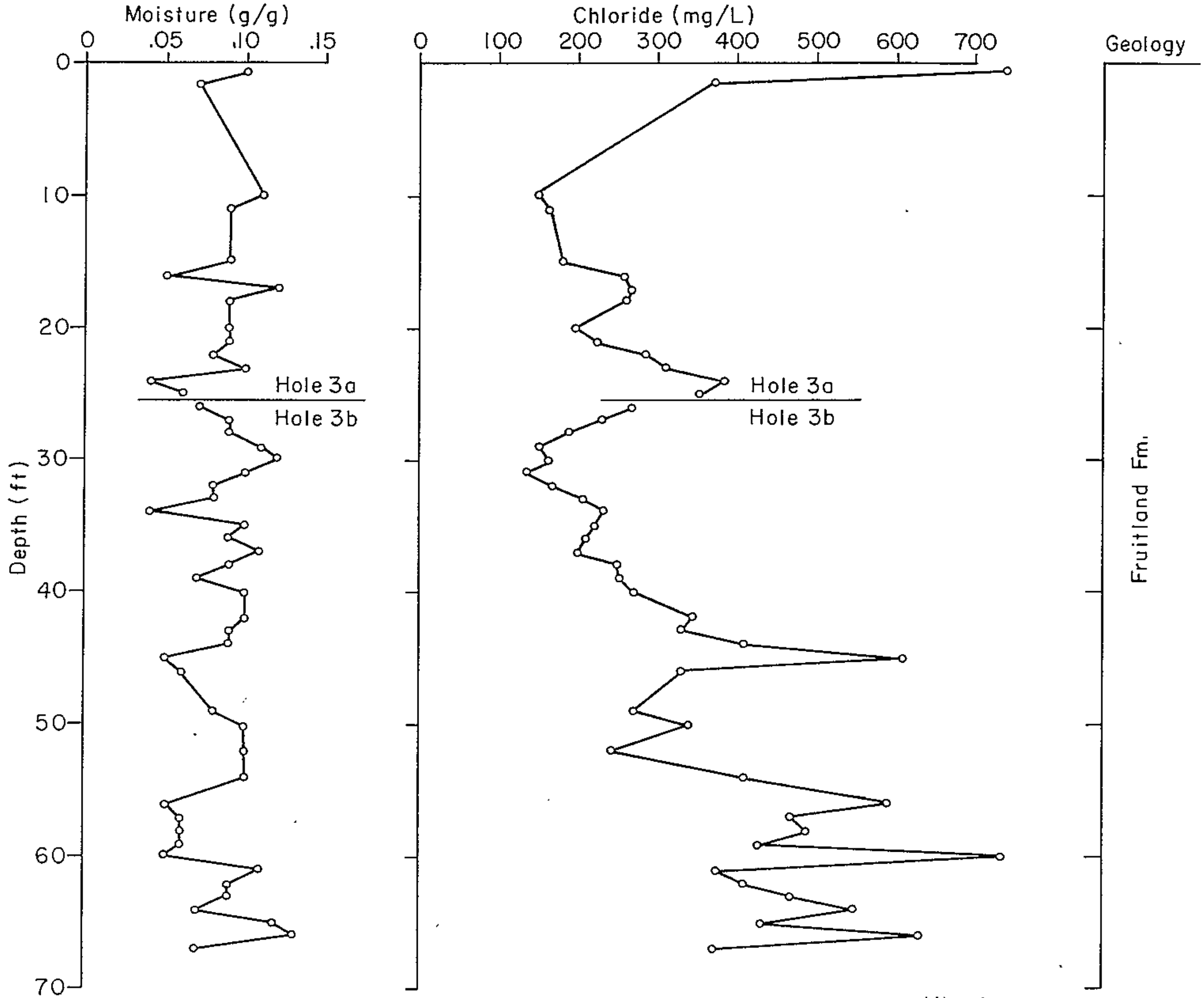

Figure 6. Results from Hole 3, badlands

water table. Only one sample was taken from this interval, at the very bottom of the core. Because this sample contained swelling clay it took up most of the extraction water, yielding too little extract after shaking for a chloride measurement without further dilution so is not shown on Figure 2.

Water was reached at a depth of approximately 45 ft at this site. This is not the regional water level because the coal in the Yazzie area is dry, based on a Utah International hole (no. 4). The water encountered occurs in the base of the alluvium, where it is apparently perched on the top of the Fruitland Formation. A probable source of this water is the large drainage-diversion ditch which parallels the road here on the north side. The floor of the ditch lies approximately 5 ft above the floor of the depression sampled or 50 ft above the saturated zone encountered.

Moisture ranges from 0.06 to 0.28 g/g; median value is 0.17 g/g (Figure 7). Lower values are associated with the upper part of the alluvium (drained) and the Fruitland Formation. Higher moisture values are associated with the spoil, which is clayey, and with the lower part of the alluvium, where some water is apparently perched at the alluvium/Fruitland contact.

The chloride/depth profile (Figure 7) may be divided into two distinct segments: an upper, post-reclamation segment, corresponding generally with the spoil (0-25 ft), and a lower, pre-reclamation segment, corresponding to the alluvium and bedrock (25-69 ft). In the lower segment, chloride content is similar to that in the Fruitland Formation elsewhere (Holes 2 and

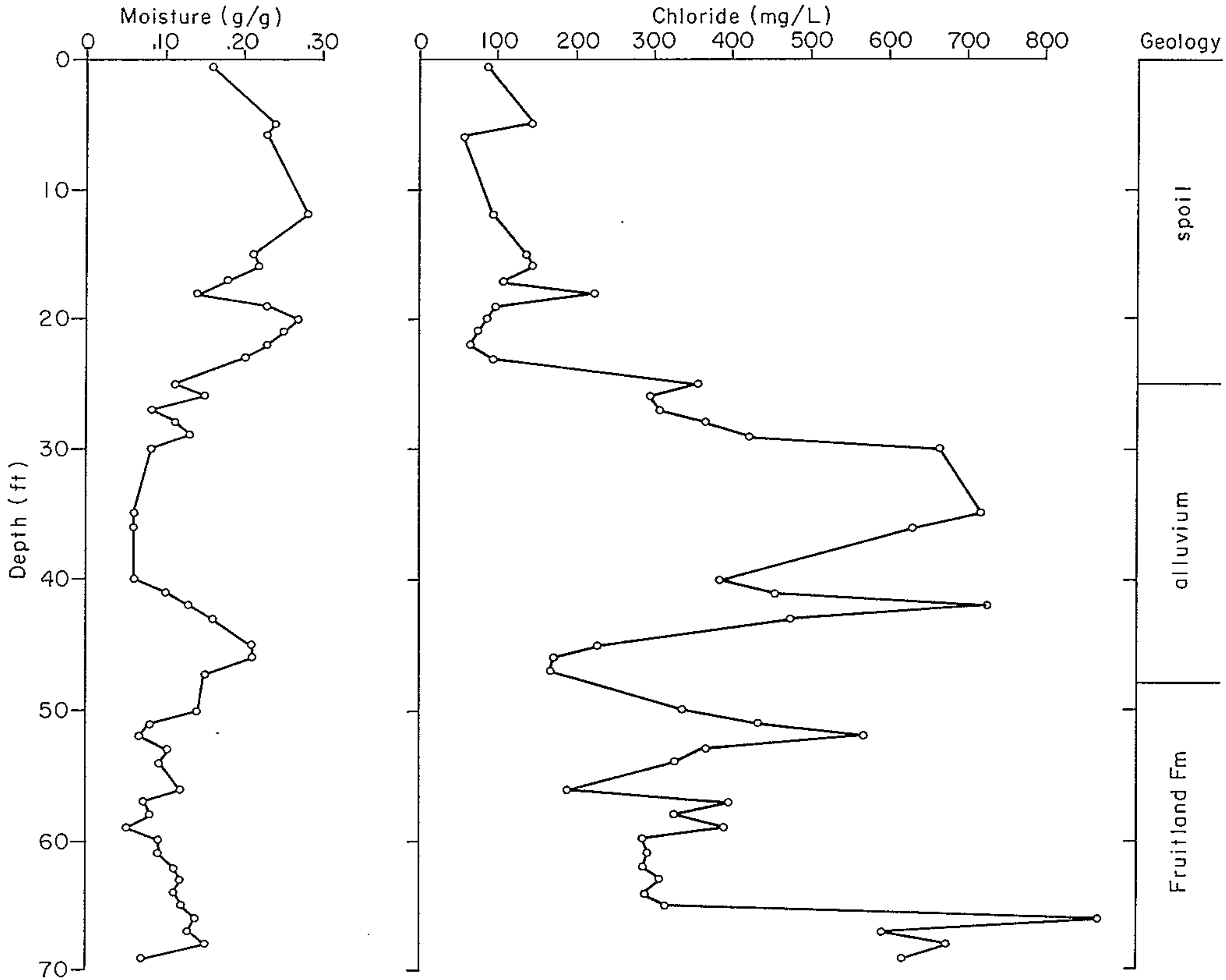

Figure 7. Results from Hole 4, reclaimed area/depression

3). Clsw is 516 mg/L for this segment and 209 mg/L in the upper segment (Table 1). Recharge is higher in the upper segment, judging from the lower chloride values and higher moisture content. Using the modern precipitation value, recharge for the lower (pre-reclamation) segment is 0.01 inch/yr, whereas, that for the upper (post-reclamation) segment is 0.02 inch/yr. However, this site is subject to runon, so P should be increased by some undetermined amount. Even if runon increases the amount of water reaching the depression by a factor of 5 (i.e., P = 28.5 inches/yr), and all of it is taken up as recharge, the calculated recharge would only be 0.08 inch/yr. More realistically, runon is probably less and most of the ponded water evaporates in such an arid climate. Salt cedars, growing around the edge of the floor of the depression, also extract water that might otherwise become recharge.

Although pre-mining and reclamation recharge values are of the same order of magnitude, recharge appears to have been at least doubled by reclamation and the presence of depressions. The actual amount of even the enhanced recharge, however, is quite small (on the order of a few hundredths of an inch/yr).

Hole 5: Reclaimed Area - flat (Yazzie Area)

This setting was selected to learn the difference in recharge through a nondepression setting in a reclaimed area. In such a setting, the effect of reclamation alone might be assessed (without the effect of the depression).

Samples for this setting were collected from a hole located approximately 150 ft to the northeast of Hole 4, next to the road to Yazzie Ramp No. 1. The ground surface lies approximately 15 ft above the floor of the depression sampled in Hole 4. A total of 61 ft was penetrated at this site. The first 47 ft were spoil, the next 10 ft were alluvium and the remaining 4 ft were Fruitland Formation (Appendix A).

The ground-water situation here is the same as that described for the previous site (Hole 4). Perched water was encountered in the alluvium above the Fruitland Formation at a depth of 50 ft. The floor of the nearby diversion ditch lies approximately 10 ft below the surface where Hole 5 was drilled or 40 ft above the saturated zone encountered.

Moisture content is slightly lower than that at Hole 4, ranging from 0.11 g/g to 0.44 g/g. The median value is 0.18 g/g (Figure 8). Highest moisture content is associated with the base of the alluvium, just above the contact with the Fruitland Formation.

As in Hole 4, the chloride profile consists of 2 distinct segments. The upper segment extends to the base of the spoil, whereas, the lower segment is associated with the alluvium and Fruitland Formation. Median Clsw is 206 mg/L in the upper segment and 439 mg/L in the lower segment. Chloride is low where moisture is high at the base of the alluvium (Figure 8).

Recharge determined for the lower (pre-reclamation) segment is 0.01 inch/yr and that for the upper (post-reclamation) segment is 0.02 inch/yr (Table 3). Thus, it again appears that reclamation has doubled recharge. However, the resulting recharge values are of the same order of magnitude and very small.

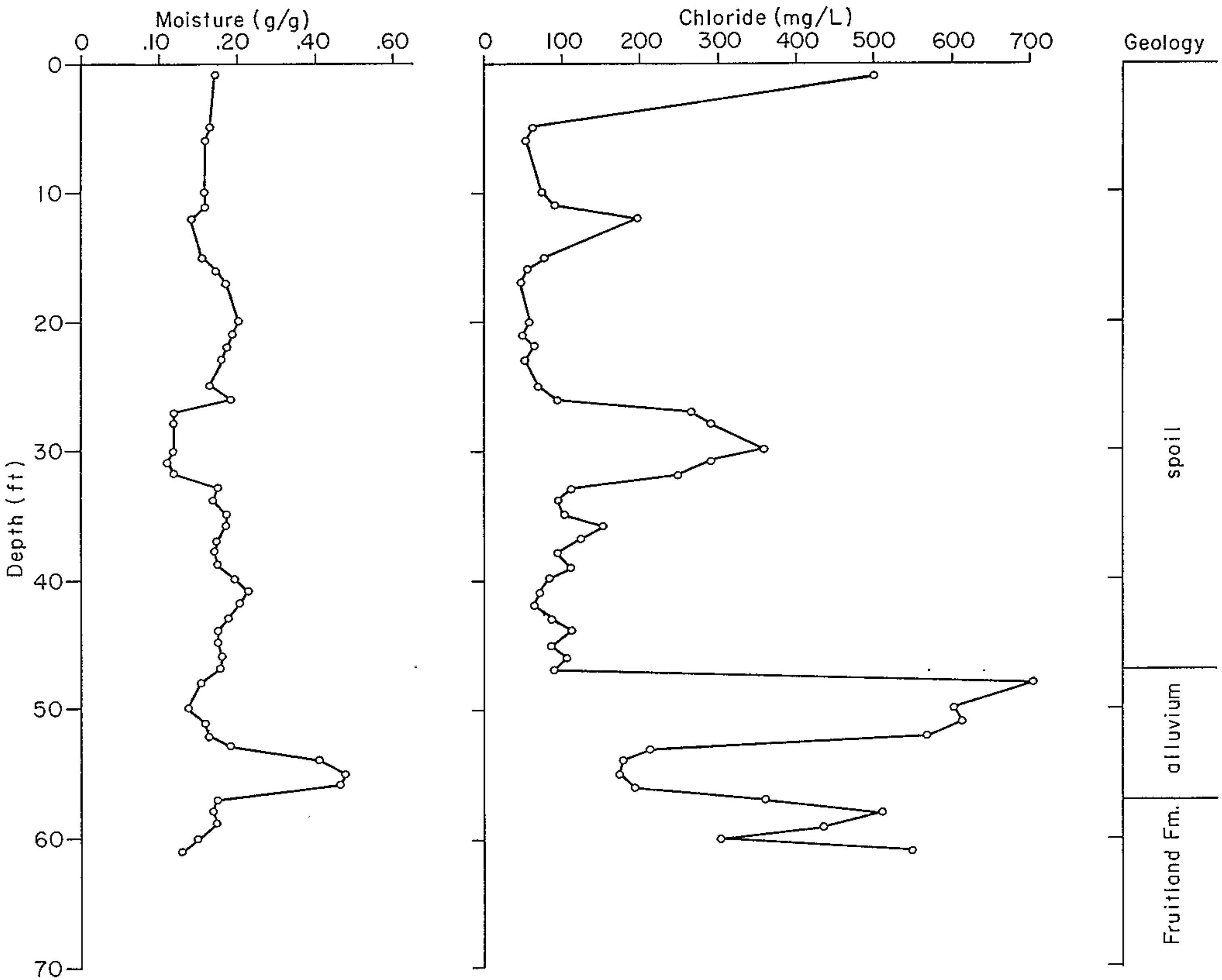

Figure 8. Results from Hole 5, reclaimed area/flat

SUMMARY AND CONCLUSIONS

Recharge was found to be lowest in the Valley-Bottom setting (0.002 inch/yr). The reason for the low value here is uncertain. Recharge in undisturbed Fruitland Formation elsewhere is 0.01 inch/yr. At the Upland Flat and reclaimed areas, recharge is 0.02 inch/yr. The reasons for the higher recharge include runon and the presence of more permeable spoil at the surface. Although reclamation appears to have doubled recharge, the total amount is small: a few hundredths of an inch per year.

The landscape settings sampled should provide a means of mapping recharge at the Navajo mine fairly well. One setting not sampled is alluvial channels. The chloride method would only give a minimum recharge value in such settings because water added by stream flow must also be taken into account. If further work is undertaken, such a setting should be included.

The top of the water table was not sampled because drilling rarely reached it. This would have provided a check of Clsw determinations inasmuch as average chloride content of the unsaturated zone and at the water table should be the same. Drilling depth was determined by auger refusal (bit did not advance in 10-15 minutes of drilling). Calcite-cemented mudstone or sandstone was usually to blame. Replacing the core barrel with a center plug should permit straight drilling through such materials in the future. The plug has teeth and thus assists the bit in penetrating hard zones. Coring could be resumed below such zones and greater total depths should be achieved. A center plug was requested, but the drilling contractor failed to bring it to the job.

The chloride peak at Hole 2 is twice as high as at other holes. It is also very shallow (0.75 ft). This may be the result of enhanced chloride concentrations in local precipitation due to emissions from the Four Corners Power Plant. Data on the chloride content of flue gas from this generating station are not available. However, the chloride content of Fruitland coal is 9-162 mg/L, averaging 60 mg/L (Utah International, Incorporated, 1984). Such chloride is insoluble, but is released by combustion. Excess chloride in precipitation in the Raton, New Mexico, area was attributed to power-plant emissions by Popp and others (1982). Such a peak was not detected in other holes because it was apparently missed in sampling.

A plot of cumulative chloride concentration _vs_ cumulative water content was prepared for all holes in order to determine whether recharge had changed over the time represented by the samples. All plots except that for Hole 2 gave more or less straight lines, indicating little or no change in recharge through time (except very recently in the case of reclaimed sites). The plot for Hole 2 was a curve, indicating a general decrease in recharge rate since approximately 7,900 yrs ago (earliest middle Holocene). It is not clear why other holes didn't reflect a change in recharge as several apparently reached even older soil water. The oldest soil water encountered is that at the bottom (74 ft) of Hole 4: 12,136 yrs B.P. (late Pleistocene).

The significance of all this is that recharge rates based on the lower parts of the chloride vs depth profiles are not modern rates but represent conditions in late Pleistocene to earliest late Holocene. As most of this time was characterized by wetter conditions than at present (Betancourt and others, 1983), these recharge rates may be taken as worst-case values. In other words, they represent the highest recharge that has occurred in the area during recent geologic time.

The recharge values obtained are considered to be reasonable. Although samples for stable-isotope and tritium analyses were not taken at Hole 2 as planned (because a hard zone ruined the core barrel), results of such analyses elsewhere generally corroborate chloride results (Allison and others, in press). Inasmuch as these various chemical methods are all based on the same assumptions, it is perhaps more useful to compare results of the chloride method with those of physical methods. The neutron-probe study conducted by the U.S. Forest Service is not yet complete, but a preliminary examination of results tends to confirm the findings of this study that recharge is low, even beneath depressions in reclaimed areas (David Scholl, U.S. Forest Service, Albuquerque, personal communication, October 1984). Where the chloride method and soil-physics methods have been applied to the same site, results have been found to be comparable (Phillips and others, 1984). The chloride method has worked well at both the Navajo mine and in the Salt Lake Coal Field (Stone, 1984b) so should prove useful in other active or potential coal-mining areas as well.

ACKNOWLEDGEMENTS

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APPENDIX A

Brief Field Description of Samples

Hole 1 Undisturbed Valley Bottom (Bitsui Area)

Drilled on low terrace in badlands above floor of small channel

Sample No.	Depth (ft)	General Lithology
1-9	6-14	Shale, dark gray, rusty mottling
10,11	15,16	Shale, gray, silty
12	17	Sandstone, light gray, cemented, very fine grained
13	18	Shale, gray, silty
14	19	Sandstone, light gray, aa but softer
15	20	Sandstone, light gray, aa, hard
16	21	Shale, green, silty
17	22	Sandstone, gray/green, clayey
18	23	Shale, black, fissile
19-21	24-26	Sandstone, light gray, silty
22-24	27-29	Claystone, dark gray, waxy
25	30	Shale, gray with calcite masses
26	31	Shale, carbonaceous
27-34	32-39	Sandstone, light gray, carbonaceous
35	40	Shale, silty, carbonaceous
36	41	Claystone, green, waxy
37-39	42-44	Sandstone, light gray, carbonaceous
40	45	Claystone, green
41-44	46-49	Coal
45	50	Shale, very carbonaceous
46	51	Siltstone, carbonaceous
47	52	Shale, carbonaceous

Hole 1 continued

Sample No.	Depth (ft)	General Lithology
48-50	53-55	Siltstone, carbonaceous, cemented
51-53	56-58	Shale, carbonaceous, cemented
54-70	59-75	Sandstone, light gray, carbonaceous

Hole 2 Upland Flat (Area III)

Hole 2a drilled just north of diversion ditch by road that crosses it; Hole 2b drilled ~ 350 ft to east, same distance from diversion ditch

Sample No.	Depth (ft)	General Lithology
Hole 2a		
71	0.5	Blow sand
72,73	0.75, 5	Clay, dark brown, carbonaceous
74	6	Clay, red and green, mottled
75	10	Claystone, rusty
76	11	Claystone, brown, carbonaceous
77-79	14.5-16	Shale, carbonaceous
80	17	Claystone, rusty
81, 82	18, 19	Clay, green, carbonaceous
83-88	20-24.5	Claystone, green and rust, carbonaceous
89	25	Sandstone, light gray, carbonaceous, hard
Hole 2b		
243-252	30-39	Shale, dark gray-black, carbonaceous

Hole 3 Badlands (Cottonwood Arroyo Area)

Hole 3a drilled ~ 125 ft west of Utah International's Hole No. KF84 22; Hole 3b drilled ~ 125 ft to north of 3a.

Sample No.	Depth (ft)	General Lithology
Hole 3a		
90	0.5	Claystone, green
91	1.5	Sandstone, light gray, cemented
92	10	Claystone, green, rusty streaks
93	11	Claystone, carbonaceous
94	15	Claystone, rusty green, carbonaceous
95	16	Siltstone, green, cemented
96	17	Shale, black, carbonaceous
97	18	Claystone, gray, carbonaceous
98-101	20-23	Claystone, rusty green
102	24	Siltstone, gray, hard
103	25	Siltstone, aa; Claystone, green
Hole 3b		
104	26	Mudstone, dark green, carbonaceous
105-107	27-29	Mudstone aa but rusty
108	30	Shale, dark gray, very carbonaceous
109-111	31-33	Claystone, rusty green
112	34	Siltstone, light gray
113	35	Shale, gray, carbonaceous
114-116	36-38	Mudstone, rusty green
117	39	Shale, gray, carbonaceous
118-122	40-44	Shale, gray-black, carbonaceous

Hole 3b continued

Sample No.	Depth (ft)	General Lithology
123-127	45-49	Mudstone, gray, carbonaceous
128	50	Shale, dark gray, carbonaceous, coaly
129-137	51-59	Shale, dark gray, carbonaceous
138	60	Siltstone, gray, carbonaceous
139-141	61-63	Shale, gray, carbonaceous
142	64	Siltstone, gray, carbonaceous
143, 144	65, 66	Shale, gray-black, very carbonaceous
145	67	Mudstone, gray, carbonaceous

Hole 4 Reclaimed Depression (Yazzie Ramp 1)

Drilled in depression south of road; salt cedars growing around edge of depression

Sample No.	Depth (ft)	General Lithology
146	0.5	Clay, dark gray, plastic
147-152	5-17	Spoil, brown-black, clayey
153	18	Shale, gray, carbonaceous (boulder)
154-159	19-25	Spoil, aa; sandy near base
160, 161	26, 27	Alluvial sand, yellow
162	28	Alluvial clay, gray
163-173	29-47	Alluvial sand, yellow
174-189	48-65	Shale, gray, carbonaceous
190, 191	66, 67	Coal, black
192, 193	68, 69	Shale, gray, carbonaceous, coaly
194	74	Sandstone, salt-and-pepper gray, carbonaceous

Hole 5 Reclaimed Flat (Yazzie Ramp 1)

Drilled ~ 150 ft to NNE of Hole 4 on flat surface just south of road

Sample No.	Depth (ft)	General Lithology
195-199	1-11	Spoil, brown, sandy
200-201	12, 15	Spoil, shale, carbonaceous
202	16	Spoil aa; some yellow sand
203	17	Spoil, black, carbonaceous
204	20	Spoil, claystone, rusty green
205-209	21-26	Spoil, shale, carbonaceous
210-214	27-32	Spoil, sandstone, buff
215-229	33-47	Spoil, carbonaceous, coaly
230-234	48-53	Alluvial sand, yellow
235-237	54-56	Alluvial sand, gray
238	57	Shale, dark green, carbonaceous (reworked)
239-241	58-60	Shale, green, carbonaceous (in place)
242	61	Mudstone, light gray, dense

APPENDIX B

Data used for Chloride *vs* Depth Plots

Explanation

NAVMOI = Navajo Mine Hole 1

Dry Wt. Soil = weight of soil used in salt extraction

Wt. Wtr. Added = weight of deionized water used in salt extraction

NAVM01

Sample No.	Sample Depth (ft)	Moist. Content (gm/gm)	Dry Wt. Soil (gm)	Wt. Wtr. Added (gm)	Cl in Extract (ppm)	Cl in Soil Wtr. (mg/l)
1	6.00	0.11	30.36	54.58	21.00	328.85
2	7.00	0.10	34.78	61.44	13.50	235.42
3	8.00	0.09	31.85	54.91	13.00	254.62
4	9.00	0.04	29.83	55.85	10.00	531.01
5	10.00	0.11	28.19	57.84	54.00	1041.19
6	11.00	0.12	26.86	51.83	57.00	906.65
7	12.00	0.09	25.86	53.10	31.50	698.66
8	13.00	0.12	26.77	57.11	24.00	424.80
9	14.00	0.13	28.32	55.32	22.50	341.83
10	15.00	0.09	27.32	56.95	14.40	325.33
11	16.00	0.09	22.28	60.40	16.00	503.29
12	17.00	0.02	25.41	64.62	8.30	870.26
13	18.00	0.10	28.26	51.71	17.00	296.46
14	19.00	0.08	28.35	47.00	28.00	600.07
16	21.00	0.07	29.32	52.44	56.00	1413.29
17	22.00	0.08	25.08	56.16	60.00	1706.36
18	23.00	0.12	28.79	65.01	33.00	634.61
19	24.00	0.07	25.45	67.73	39.00	1389.70
20	25.00	0.07	25.55	58.74	72.00	2400.18
21	26.00	0.08	29.49	64.76	34.00	885.13
26	31.00	0.03	30.01	54.04	37.00	2321.10
27	32.00	0.05	30.84	63.21	78.00	3306.83
29	34.00	0.07	35.81	50.70	107.00	2151.54
30	35.00	0.02	23.78	79.91	20.00	3223.28
31	36.00	0.04	27.68	56.37	80.00	3818.93
32	37.00	0.05	31.03	55.77	100.50	3401.28
34	39.00	0.06	26.08	54.79	94.00	3479.91
36	41.00	0.05	28.15	61.42	46.00	1952.65
38	43.00	0.04	35.07	61.09	73.00	3076.44
39	44.00	0.08	35.86	69.62	62.00	1544.52
40	45.00	0.07	32.23	64.67	35.00	1044.64
41	46.00	0.13	17.48	57.02	72.00	1801.32
42	47.00	0.13	18.55	53.35	98.00	2099.09
43	48.00	0.14	19.59	52.81	94.00	1825.43
44	49.00	0.16	26.72	56.37	100.50	1313.05
46	51.00	0.08	26.53	69.74	44.00	1514.51
48	53.00	0.08	29.71	64.50	39.00	1109.31
50	55.00	0.08	29.14	65.37	50.00	1334.49
52	57.00	0.09	30.90	62.79	37.00	847.97
53	58.00	0.07	27.77	75.37	27.00	993.23
56	61.00	0.10	27.87	66.21	36.00	885.88
58	63.00	0.09	30.19	76.01	25.00	688.06
61	66.00	0.10	32.20	65.57	44.00	912.20
65	70.00	0.09	35.42	70.25	38.60	894.35
67	72.00	0.09	35.91	66.14	84.00	1714.78
70	75.00	0.06	34.79	66.38	69.00	2080.72

NAVM02

Sample No.	Sample Depth (ft)	Moist. Content (gm/gm)	Dry Wt. Soil (gm)	Wt. Wtr. Added (gm)	Cl in Extract (ppm)	Cl in Soil Wtr. (mg/l)
71	0.50	0.09	31.01	66.11	12.00	287.27
72	0.75	0.19	22.26	67.53	101.50	1595.52
73	5.00	0.17	29.17	64.05	31.00	390.92
74	6.00	0.11	29.87	67.53	13.00	258.53
75	10.00	0.15	23.65	76.09	12.00	252.94
76	11.00	0.16	28.70	77.82	9.00	148.71
77	14.50	0.29	18.42	60.11	14.50	164.44
78	15.00	0.28	19.76	67.09	12.50	149.88
79	16.00	0.20	20.22	78.61	8.80	174.62
80	17.00	0.19	28.07	78.49	8.80	132.12
81	18.00	0.16	26.02	66.41	7.00	108.37
82	19.00	0.15	28.04	79.85	6.20	118.26
83	20.00	0.16	32.42	68.06	13.50	179.03
84	21.00	0.13	28.78	68.79	6.80	124.64
85	22.00	0.12	25.29	73.82	7.20	179.74
86	23.00	0.11	25.87	68.94	6.60	158.29
88	24.50	0.12	28.51	69.80	7.20	148.45
89	25.00	0.03	30.27	62.53	4.00	242.27
243	30.00	0.13	35.32	67.62	5.70	85.45
244	31.00	0.13	35.03	69.81	6.20	98.82
245	32.00	0.12	32.18	65.19	10.00	164.38
246	33.00	0.09	30.78	59.19	8.00	177.64
247	34.00	0.09	34.64	68.09	9.00	188.30
248	35.00	0.09	29.12	51.24	22.00	424.36
249	36.00	0.10	26.86	71.39	6.00	166.91
250	37.00	0.09	35.47	73.36	4.90	107.80
251	38.00	0.09	36.64	75.51	2.50	56.94
252	39.00	0.10	35.91	73.13	3.40	67.44

NAVM03

Sample No.	Sample Depth (ft)	Moist. Content (gm/gm)	Dry Wt. Soil (gm)	Wt. Wtr. Added (gm)	Cl in Extract (ppm)	Cl in Soil Wtr. (mg/l)
90	0.50	0.10	22.76	84.95	20.00	736.10
91	1.50	0.07	26.09	73.76	9.60	369.17
92	10.00	0.11	34.71	71.99	7.40	146.02
93	11.00	0.09	31.16	66.28	7.00	161.53
94	15.00	0.09	32.88	64.55	8.10	180.37
95	16.00	0.05	28.83	63.95	5.40	257.58
96	17.00	0.12	30.08	68.17	14.00	267.45
97	18.00	0.09	29.88	59.84	12.00	263.46
98	20.00	0.09	32.93	60.01	10.00	196.19
99	21.00	0.09	34.65	56.44	12.00	222.67
100	22.00	0.08	24.99	58.33	9.20	284.22
101	23.00	0.10	37.51	61.12	18.60	308.62
102	24.00	0.04	30.05	66.59	6.60	382.57
103	25.00	0.06	25.63	65.58	8.30	357.94
104	26.00	0.07	29.73	77.16	7.30	267.24
105	27.00	0.09	28.86	75.16	7.80	233.73
106	28.00	0.09	32.16	64.37	8.70	185.90
107	29.00	0.11	30.22	70.04	7.40	154.98
108	30.00	0.12	26.11	61.06	8.10	163.54
109	31.00	0.10	24.02	61.96	5.20	137.39
110	32.00	0.08	29.96	66.13	5.70	166.08
111	33.00	0.08	36.07	64.72	9.00	207.55
112	34.00	0.04	27.16	56.91	4.90	233.30
113	35.00	0.10	24.95	55.00	9.80	222.15
114	36.00	0.09	32.23	54.33	11.60	214.09
115	37.00	0.11	32.32	60.10	11.50	202.90
116	38.00	0.09	25.41	61.70	8.70	247.51
117	39.00	0.07	25.50	56.34	8.40	252.64
118	40.00	0.10	26.42	69.67	10.50	272.93
120	42.00	0.10	31.16	63.31	16.50	342.43
121	43.00	0.09	31.64	64.45	14.50	330.81
122	44.00	0.09	28.94	54.81	18.50	410.73
123	45.00	0.05	35.17	61.59	16.50	612.75
124	46.00	0.06	23.48	70.85	6.30	332.89
127	49.00	0.08	32.19	65.44	11.00	270.32
128	50.00	0.10	28.50	60.52	16.00	340.24
130	52.00	0.10	33.50	62.14	13.50	244.96
132	54.00	0.10	39.18	62.44	26.00	411.71
134	56.00	0.05	37.44	62.50	17.50	594.96
135	57.00	0.06	31.75	64.27	14.00	464.45
136	58.00	0.06	40.62	77.06	15.00	482.45
137	59.00	0.06	32.65	72.05	12.00	429.93
138	60.00	0.05	36.87	66.53	19.50	737.31
139	61.00	0.11	32.43	57.67	24.00	377.08
140	62.00	0.09	33.03	59.54	21.50	409.06
141	63.00	0.09	34.13	71.71	19.60	468.11
142	64.00	0.07	29.44	78.13	13.50	547.73
143	65.00	0.12	30.95	73.33	21.00	432.06

Sample No.	Sample Depth (ft)	Moist. Content (gm/gm)	Dry Wt. Soil (gm)	Wt. Wtr. Added (gm)	Cl in Extract (ppm)	Cl in Soil Wtr. (mg/l)
144	66.00	0.13	26.95	62.17	37.00	635.52
145	67.00	0.07	34.17	69.68	13.50	368.50

NAVM04

Sample No.	Sample Depth (ft)	Moist. Content (gm/gm)	Dry Wt. Soil (gm)	Wt. Wtr. Added (gm)	Cl in Extract (ppm)	Cl in Soil Wtr. (mg/l)
146	0.50	0.16	29.25	62.37	6.40	85.80
147	5.00	0.24	28.08	74.56	13.00	143.57
148	6.00	0.23	31.63	72.27	6.00	59.07
149	12.00	0.28	32.52	65.17	13.00	93.80
150	15.00	0.21	29.34	54.93	15.00	136.85
151	16.00	0.22	27.36	58.37	15.00	144.11
152	17.00	0.18	36.94	59.23	12.00	109.50
153	18.00	0.14	32.58	60.80	17.00	224.43
154	19.00	0.23	30.07	73.89	9.00	98.12
155	20.00	0.27	33.89	72.81	11.00	87.18
156	21.00	0.25	35.66	66.60	10.50	78.00
157	22.00	0.23	37.73	59.09	9.10	62.24
158	23.00	0.20	38.44	76.00	9.80	97.06
159	25.00	0.11	47.52	75.32	24.00	358.73
160	26.00	0.15	37.36	62.49	27.00	292.56
161	27.00	0.08	37.00	61.09	14.50	305.74
162	28.00	0.11	33.31	68.80	19.00	363.63
163	29.00	0.13	36.53	68.03	28.50	422.39
164	30.00	0.08	38.55	68.51	28.50	661.55
165	35.00	0.06	35.80	66.10	22.00	717.09
166	36.00	0.06	38.67	78.94	20.00	629.96
167	40.00	0.06	42.39	77.53	12.00	382.36
168	41.00	0.10	43.62	72.30	28.50	456.50
169	42.00	0.13	36.77	63.81	56.00	725.09
170	43.00	0.16	41.79	77.87	40.00	474.49
171	45.00	0.21	42.36	73.71	28.00	226.85
172	46.00	0.21	45.97	75.98	21.50	173.24
173	47.00	0.15	32.83	63.50	13.20	167.44
175	50.00	0.14	33.39	79.24	20.00	338.35
176	51.00	0.08	35.97	72.55	16.50	431.43
177	52.00	0.07	29.43	65.15	18.00	568.74
178	53.00	0.10	33.03	62.50	20.00	362.45
179	54.00	0.09	28.48	67.14	12.50	324.95
180	56.00	0.12	40.08	77.44	11.40	189.17
181	57.00	0.07	30.58	70.03	12.50	395.17
182	58.00	0.08	29.07	66.36	12.00	323.58
183	59.00	0.05	32.79	64.27	10.50	390.91
184	60.00	0.09	33.13	62.39	13.00	285.10
185	61.00	0.09	28.70	63.68	12.00	292.68
186	62.00	0.11	25.32	59.41	12.80	283.51
187	63.00	0.12	27.55	57.54	17.00	306.00
188	64.00	0.11	24.00	60.65	12.00	286.04
189	65.00	0.12	26.56	65.99	15.50	317.11
190	66.00	0.14	20.58	57.72	42.00	865.40
191	67.00	0.13	16.32	50.12	25.50	596.67
192	68.00	0.15	19.80	52.22	38.00	672.96
193	69.00	0.07	29.32	59.44	21.50	617.83

NAVM05

Sample No.	Sample Depth (ft)	Moist. Content (gm/gm)	Dry Wt. Soil (gm)	Wt. Wtr. Added (gm)	Cl in Extract (ppm)	Cl in Soil Wtr. (mg/l)
195	1.00	0.14	27.98	67.70	29.00	500.56
196	5.00	0.13	28.86	70.88	3.20	60.54
197	6.00	0.12	29.17	61.22	3.10	52.72
198	10.00	0.12	36.16	73.75	4.40	72.62
199	11.00	0.12	34.40	81.33	4.60	90.91
200	12.00	0.08	31.05	66.73	7.20	199.47
201	15.00	0.11	34.58	73.74	4.10	76.98
202	16.00	0.13	33.07	66.35	3.60	56.41
203	17.00	0.17	32.13	69.91	3.80	47.57
204	20.00	0.20	31.16	85.16	4.40	59.68
205	21.00	0.18	34.05	69.90	4.20	49.24
206	22.00	0.17	37.69	81.88	5.00	65.65
207	23.00	0.16	37.69	81.88	4.20	55.37
208	25.00	0.13	35.72	76.36	4.40	72.19
209	26.00	0.18	31.05	67.27	8.10	96.58
210	27.00	0.04	32.81	61.23	5.50	264.28
211	28.00	0.04	29.04	62.49	4.70	287.05
212	30.00	0.04	32.00	60.78	7.60	359.42
213	31.00	0.03	32.10	57.61	4.90	287.24
214	32.00	0.04	31.14	64.78	4.20	248.73
215	33.00	0.15	35.61	74.30	8.20	113.98
216	34.00	0.14	30.37	60.28	7.00	97.94
217	35.00	0.17	31.00	62.86	8.20	100.35
218	36.00	0.17	29.47	61.89	12.00	149.82
219	37.00	0.15	32.44	60.49	9.60	123.43
220	38.00	0.14	35.27	71.10	6.40	92.21
221	39.00	0.15	33.72	63.67	8.40	108.27
222	40.00	0.19	27.57	66.29	6.30	80.29
223	41.00	0.23	29.76	63.86	7.60	71.60
224	42.00	0.21	29.98	60.64	6.80	64.14
225	43.00	0.18	36.51	71.63	8.00	85.32
226	44.00	0.15	25.88	57.66	7.80	115.70
227	45.00	0.15	24.47	50.63	6.20	85.70
228	46.00	0.16	25.52	60.51	7.30	108.23
229	47.00	0.16	33.13	74.19	6.20	87.43
230	48.00	0.10	40.13	79.37	35.00	702.45
231	50.00	0.07	43.57	73.49	26.00	608.20
232	51.00	0.12	42.40	77.18	41.00	612.01
233	52.00	0.13	43.10	76.46	40.00	565.05
234	53.00	0.18	40.73	75.00	21.50	214.64
235	54.00	0.41	30.23	63.64	34.00	176.45
236	55.00	0.47	27.00	58.26	38.00	175.41
237	56.00	0.46	24.19	61.98	35.00	194.61
238	57.00	0.15	35.71	70.52	27.00	358.12
239	58.00	0.14	26.69	57.81	33.00	511.93
240	59.00	0.15	31.95	74.15	28.00	435.59
241	60.00	0.10	30.29	63.23	14.00	301.86
242	61.00	0.06	32.99	66.76	16.00	549.76

APPENDIX C

Data Used For Cumulative Chloride *vs* Cumulative Water Plot (Hole 2)

Explanation

NAVMO2 = Navajo Mine Hole 2

Vol. Water Content = volumetric water content
(gravimetric water content • bulk density)

NAVM02

Sample No.	Sample Interval Length (m)	Vol. Water Content (cu m/cu m)	Cl in Soil (g/cu m)	Cl in Soil (g/sq m)	Cum. Cl in Soil (g/sq m)	Vol. Water Cont. (m)	Cum. Vol. Wtr. Content (m)
71	0.19	0.13	36.20	6.88	6.88	.02	0.02
72	0.69	0.27	424.41	292.84	299.72	.18	0.21
73	0.80	0.24	93.04	74.43	374.15	.19	0.40
74	0.76	0.15	39.81	30.26	404.41	.12	0.51
75	0.76	0.21	53.12	40.37	444.78	.16	0.67
76	0.69	0.22	33.31	22.98	467.76	.15	0.83
77	0.61	0.41	66.76	40.73	508.49	.25	1.08
78	0.23	0.39	58.75	13.51	522.00	.09	1.17
79	0.30	0.28	48.89	14.67	536.67	.08	1.25
80	0.30	0.27	35.14	10.54	547.21	.08	1.33
81	0.30	0.22	24.27	7.28	554.49	.07	1.40
82	0.30	0.21	24.83	7.45	561.94	.06	1.46
83	0.30	0.22	40.10	12.03	573.98	.07	1.53
84	0.30	0.18	22.68	6.81	580.78	.05	1.58
85	0.30	0.17	30.20	9.06	589.84	.05	1.63
86	0.38	0.15	24.38	9.26	599.10	.06	1.69
88	0.30	0.17	24.94	7.48	606.58	.05	1.74
89	0.84	0.04	10.18	8.55	615.13	.04	1.78
243	0.91	0.18	15.55	14.15	629.28	.17	1.94
244	0.30	0.18	17.99	5.40	634.68	.05	2.00
245	0.30	0.17	27.62	8.28	642.96	.05	2.05
246	0.30	0.13	22.38	6.71	649.68	.04	2.09
247	0.30	0.13	23.73	7.12	656.80	.04	2.12
248	0.30	0.13	53.47	16.04	672.84	.04	2.16
249	0.30	0.14	23.37	7.01	679.85	.04	2.20
250	0.30	0.13	13.58	4.07	683.92	.04	2.24
251	0.30	0.13	7.17	2.15	686.08	.04	2.28
252	0.15	0.14	9.44	1.42	687.49	.02	2.30