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OAK RIDGE Y-12 PLANT

MARTIN MARIETTA

EVALUATION OF CAVITY OCCURRENCE IN THE MAYNARDVILLE LIMESTONE AND THE COPPER RIDGE DOLOMITE AT THE Y-12 PLANT USING LOGISTIC AND GENERAL LINEAR MODELS

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November 1994

Prepared for the
Environmental Management Department
Health, Safety, Environment, and
Accountability Organization
Oak Ridge Y-12 Plant
Oak Ridge, Tennessee 38731

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MARTIN MARIETTA ENERGY SYSTEMS, INC.
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ABBREVIATIONS

Ccr	Copper Ridge Dolomite
Cmn	Maynardville Limestone
DBC	Depth of water zone above or below the Cmn - Ccr lithologic contact
Depth	Depth of water zone below ground surface (ft)
D1	Dummy variable used in logistic model
D2	Dummy variable used in logistic model
East	East coordinate in feet (in Y-12 grid)
Elev	Elevation of the water zone in feet above mean sea level
GLM	General Linear Models
H	Well encountering a particular water zone is located on a hill
Loc	Location of the well in which the water zone is encountered (i.e., on a ridge, or hill, or in a valley)
LOG	Logistic model
North	North coordinate in feet (in Y-12 grid)
ORR	Oak Ridge Reservation
Size	Size of a cavity as determined during drilling; the length over which the drill string dropped
Type	Type of water zone (used in initial GLM models) to indicate if the zone was a cavity, fracture or water zone
R	Well encountering a particular water zone is located on a ridge
V	Well encountering a particular water zone is located in a valley

EXECUTIVE SUMMARY

Several waste disposal sites are located on or adjacent to the karstic Maynardville Limestone (Cmn) and the Copper Ridge Dolomite (Ccr) at the Oak Ridge Y-12 Plant. These formations receive contaminants in groundwaters from nearby disposal sites, which can be transported quite rapidly due to the karst flow system. In order to evaluate transport processes through the karst aquifer, the solutional aspects of the formations must be characterized. As one component of this characterization effort, statistical analyses were conducted on the data related to cavities in order to determine if a suitable model could be identified that is capable of predicting the probability of cavity size or distribution in locations for which drilling data are not available. Existing data on the locations (East, North coordinates), depths (and elevations), and sizes of known conduits and other water zones were used in the analyses.

Two different models were constructed in the attempt to predict the distribution of cavities in the vicinity of the Y-12 Plant: General Linear Models (GLM), and Logistic Regression Models (LOG). Each of the models attempted was very sensitive to the data set used. Models based on subsets of the full data set were found to do an inadequate job of predicting the behavior of the full data set. The fact that the Ccr and Cmn data sets differ significantly is not surprising considering the hydrogeology of the two formations differs. Flow in the Cmn is generally at elevations between 600 and 950 ft and is dominantly strike parallel through submerged, partially mud-filled cavities with sizes up to 40 ft, but more typically less than 5 ft. Recognized flow in the Ccr is generally above 950 ft elevation, with flow both parallel and perpendicular to geologic strike through conduits, which tend to be large than those on the Cmn, and are often not fully saturated at the shallower depths.

The LOG models formulated were not successful in predicting the probability of cavity occurrence at specific locations within the Ccr and Cmn. In the LOG models, the East and North coordinates were not important variables in the Ccr data, and the East coordinate was not an important variable in the Cmn data set. Hence, with a given elevation and north value, cavity presence or absence would be predicted regardless of the east value in the Cmn. The model is insensitive to the east coordinate, which is reasonable given that the dominant flow direction in the Cmn is along geologic strike (E-W). Both the GLM and LOG analyses suggest that cavity size and presence in the Cmn is a strong function of north and elevation (or depth).

The presence or absence of a cavity at a given location can not be predicted using the models attempted because not all the variables, which define a point in space are significant in the models. Numerous other controlling variables were not included in the model due to lack of data at many of the locations. For instance, the presence or absence of a cavity is likely to be function of lithology, zone thicknesses, and matrix porosity values, and such variables would give an indication of the ease of dissolution. These types of data, in addition to hydrologic data, could be examined on localized areas where sufficiently detailed data are available, but were not considered in this report because these data are not known at most well bore locations. Given the complexities of the karst flow system, it is possible that other models, which incorporate geologic data would also be inadequate in predicting cavity occurrence, because insufficient data are available at most locations.

INTRODUCTION

Karst aquifers can have a profound effect on contaminant transport rates when waste disposal facilities are located on or adjacent to them. Several waste disposal sites are located adjacent to the karst Cambrian Maynardville Limestone (Cmn), and on the Cambrian Copper Ridge Dolomite (Ccr) at the U.S. Department of Energy Y-12 Plant on the Oak Ridge Reservation (ORR) in Oak Ridge, TN. The Cmn is the upper member of the Conasauga Group and the Ccr is the lower member of the Knox Group. The study area in this report is along Bear Creek Valley near the Y-12 Plant in the lower Knox Group (Ccr) which forms Chestnut Ridge, and the upper Conasauga Group (see Fig. 1).

The Cmn overlies the Cambrian Nolichucky Shale and was deposited in an upward shallowing subtidal to intertidal carbonate platform environment (Goldstrand, in press). The Cmn has previously been subdivided into six informal zones where the bottom is identified as zone 2 and the top is zone 6. Zones 1 and 7 are transitional between the Cmn and the Nolichucky Shale, and the Cmn and the Ccr, respectively (Shevenell et al., 1992). The following lithologic descriptions are summarized from Goldstrand (in press). Zone 2 consists dominantly of thrombolitic limestone, and solution zones and vugs are common and related to dissolution along interbeds of carbonate mudstone and interfaces of shale strings. Solution features are also due to dedolomitization and localized oxidation of pyrite. Zone 3 consists of interbedded thrombolitic limestones with subtidal oncolitic, and oolitic limestones. Dissolution features are more commonly associated with the thrombolitic limestones. Zone 4 consists of coarsely crystalline peloidal and oolitic limestone, and secondary porosity is limited. However, dissolution features found in zone 4 are related to dissolution of intervening carbonate mudstones interbedded with stromatolitic and thrombolitic limestones. Zone 5 consists of laterally extensive oolitic limestone with interbeds of shale and carbonate mudstone. Dedolomitization accounts for most of the secondary micro-porosity. The cavernous intervals in this zone are associated with fractures or faults. Zone 6 consists of stromatolitic dolostone and dolomitic limestone. This unit has higher porosities than other Cmn zones with vugs and cavities being formed by dissolution of evaporite nodules. Dedolomitization is common throughout this zone and is responsible for much of the micro-porosity development (Goldstrand, in press).

Several ideas and concepts pertaining to the nature, extent, and the behavior of the karst aquifers at the Y-12 Plant require refinement. Results from a recent drilling project appear in Shevenell et al. (1992). The geochemical characteristics of the groundwaters as they relate to identifying quick flow water intervals through fractures and conduits have previously been evaluated (Shevenell, in press). Detailed lithologic descriptions, diagenetic interpretations, and evaluation of secondary porosity development are documented in Goldstrand (in press) and Goldstrand et al. (in prep.). The ultimate objective of the overall studies of the Cmn is to be able to predict the distribution of conduits and, therefore, flow paths for groundwater and potential contaminant transport in these rock units.

The purpose of conducting statistical analyses on the data related to cavities at the Y-12 Plant is to determine if a suitable model can be identified which is capable of predicting cavity size or the probability of cavity occurrence in locations for which drilling data are not available. If an acceptable model can be identified, then the analyses are to be used to predict the locations and/or sizes of cavities throughout the Cmn and Ccr. Cavity occurrence is associated with rapid fluid velocities and Locally high hydraulic conductivities are associated with cavity occurrence and rapid fluid velocities. The distribution of cavities, if they can be predicted, can be used to conduct groundwater flow modeling and predict possible, preferential flow paths.

BACKGROUND

To effectively evaluate groundwater and surface water contamination and contaminant migration from waste sites at the Y-12 Plant, a Comprehensive Groundwater Monitoring Plan (Comprehensive Plan) was developed to guide monitoring of surface water and groundwater quality at the Y-12 Plant (Geraghty and Miller, 1990). A previous report (Shevenell et al., 1992) describes the implementation of the Maynardville Limestone exit pathways project, which is a portion of the Comprehensive Plan (Maynardville

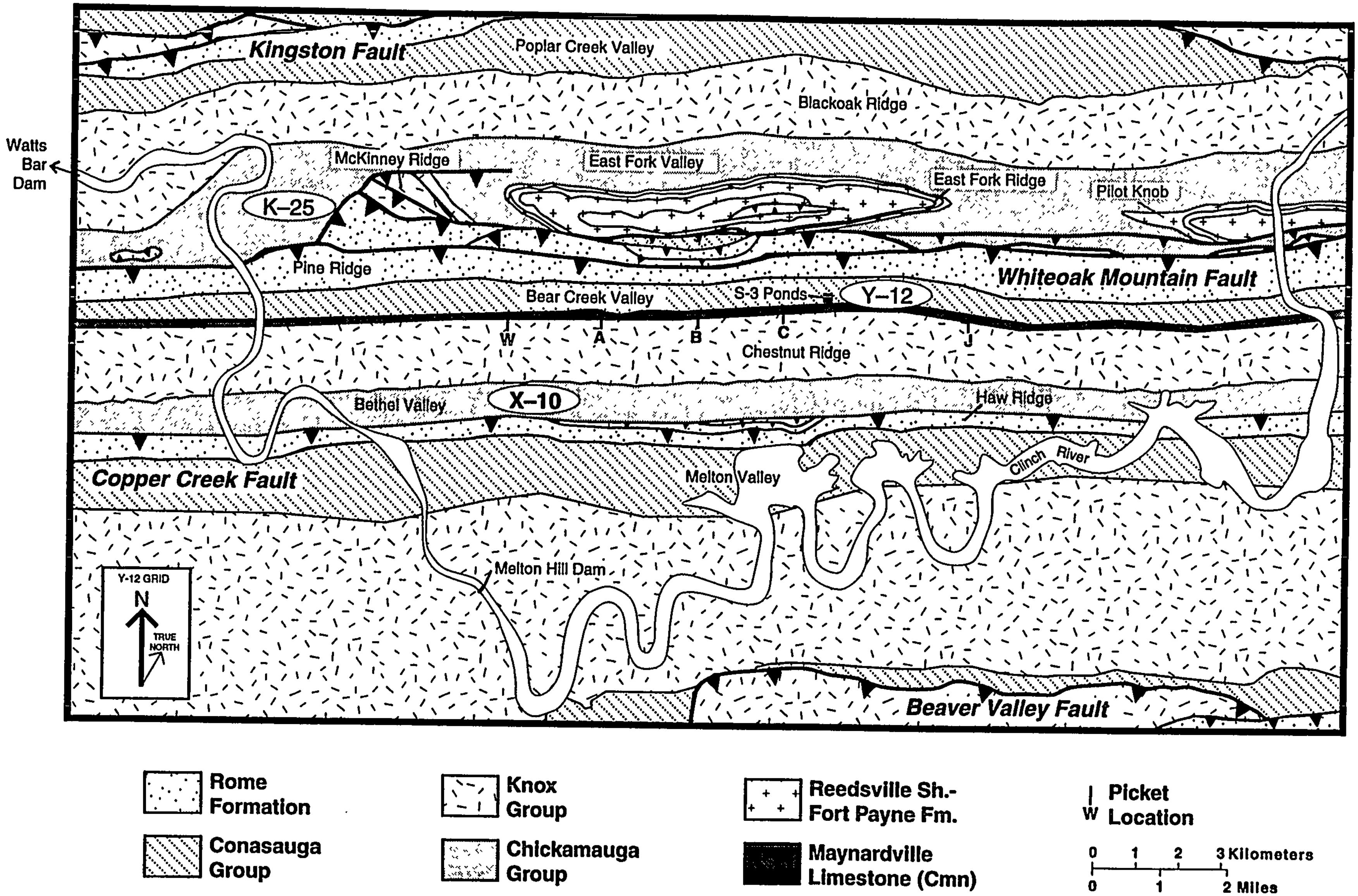

Figure 1. Generalized Geologic Map of the Oak Ridge Reservation. Modified from Hatcher, et al. (1992).

Project). The Cmn, which underlies the axis of Bear Creek Valley (BCV), is considered to be the primary pathway for groundwater leaving the Y-12 Plant (King and Haase, 1988). Because the Cmn and the Ccr are in hydraulic continuity, the cavities in both formations are investigated in this report.

Over 800 water producing intervals have been identified in the Cmn and Ccr, and additional intervals continue to be encountered as drilling proceeds. The data used in this report are from Jones et al. (1992) and Dreier et al. (1993). Of the 800 intervals noted thus far, 36% have been identified as cavities, 32% have been identified as fractures, and 32% as slow flow water producing intervals (see Appendix A for listing of the intervals). Cavities are noted when an obvious drop in the drill string occurs during drilling; fractures are noted when cuttings or core have oxidized or altered surfaces, or if significant drilling rig chatter occurs in an interval. Either of the two categories (fracture or cavity) may or may not be associated with water production, thought they often are. Water zones are defined when none of the above characteristics are observed, yet small increases in water production are observed during drilling. A large percentage (66%) of wells which have been drilled in carbonate units (Cmn and Ccr) at the Y-12 Plant have encountered at least one cavity (Table 1) indicating that cavities are pervasive throughout the site.

The sizes of the cavities in the Cmn and Ccr differ somewhat in that those in the Ccr tend to be slightly larger (Table 2) with up to 23% of the encountered cavities having vertical dimensions greater than 5 ft as determined from drilling data. Often, the shallower (less than ≈150 ft) conduits in the Ccr are at or above the water table, whereas all the conduits encountered in the Cmn are submerged, which is reasonable given that the Ccr occurs at higher elevations than the Cmn. Several of the larger, dominantly air-filled conduits in the Ccr have recently been explored at a nearby site on the ORR (Lemiszki and Rubin, pers. comm., 1993). Recent drilling data (Shevenell et al., 1992) shows that numerous, small (<5 ft), interconnected cavities are common locally within the Cmn. Data in Table 2 show the distribution of cavities by size. Note that the sizes of numerous cavities (20% in the Cmn, and 38% in the Ccr) were not noted during drilling. In many of the older wells drilled prior to 1987, only the depth to the top of a cavity was noted. In addition, it is believed that many of the older records are not accurate and may not have noted cavities when they were encountered. Recent plugging and abandonment activities at some of these older wells indicate that information such as total depths and screened interval depths where documented incorrectly during drilling (Jago, pers. comm., 1993).

Occurrence of cavities by elevation is listed in Table 3. It should be noted that the data are biased by the depths to which wells have been drilled. Few wells have been drilled to depths greater than 300 ft (elevations less than 600 to 700 ft). The Ccr is a ridge former on the ORR, hence most (73%) of the conduits occur at elevations >950 ft. No cavities have yet been encountered in the Ccr at elevations less than 700 ft (depths ≈400 ft). The Cmn subcrops in BCV (valley floor elevations ≈800 to 900 ft), and hence, most (≈83%) cavities occur at lower elevations (<950 ft).

PROCEDURE

The locations of cavities are likely to be related to many interacting variables. The following factors are believed to be important in cavity occurrence: (1) location relative to the Cmn subcrop, (2) the particular Cmn zone (ie. zone 6 contains abundant vugs (Goldstrand, in press)), (3) depth below ground surface, (4) location relative to major springs, sinkholes and faults and fractures, (5) location relative to Chestnut Ridge, and (6) location relative to crosscutting valleys (strike perpendicular valleys). Insufficient data are available on the location of individual Cmn zones because these zones have only been identified within the past few years, and all older wells do not have this information. Hence, these data could not be incorporated into a model. Items (1) and (5) were qualitatively incorporated into the models discussed below by noting if wells were drilled on the ridge, hillside or in the valley. Data for item (4) is unknown in many cases (i.e., faults and fractures) when referring to these characteristics in relation to particular water zones encountered at depth. In the particular models discussed here, the 3-D location of known cavities (north, east, depth) was selected for use in the attempt to predict cavity locations.

Table 1. Occurrence of cavities in wells drilled in the Cmn and Ccr as of August, 1992.

	Cmn	Ccr	Cmn + Ccr
Total number of wells	122	70	192
% of wells intersecting at least one cavity	67%	64%	66%
% of wells intersecting 2 or more cavities	42%	31%	38%

Table 2. Distribution of cavities by size in the Cmn and Ccr. Cavity size (Cavity size is determined on the vertical drop in the drill string during drilling.)

Distribution	Cmn	Ccr
% of Cavities with size <1 ft	16%	1%
% of Cavities with size 1 to 4.99 ft	52%	38%
% of cavities with size 5 to 9.99 ft	6%	11%
% of cavities with size >10 ft	6%	12%
% of cavities with unknown size	20%	38%

Table 3. Elevations of cavities encountered in wells in the Cmn and Ccr.

Elevation	Cmn	Ccr
<600 ft	1%	0%
600 to 699 ft	2%	0%
700 to 799 ft	7%	1%
800 to 899 ft	24%	6%
900 to 949 ft	50%	20%
950 to 999 ft	16%	28%
>1000 ft	2%	45%
	82.6% of cavities at Elev. <950 ft	73% of cavities at Elev. >950 ft

Two different classes of models were constructed in the attempt to predict the size (vertical dimension obtained from drilling records) and locations of cavities in the vicinity of the Y-12 Plant: general linear models (GLM), and logistic regression models (LOG). The statistical package SAS/STAT (SAS Institute Inc., 1992) was used to compare possible controlling variables in both models.

General Linear Model

A predictive model was sought relating the measured cavity size to its location (surveyed East and North coordinates of the well bores), depth below ground surface (Depth) or elevation above mean sea level (Elev.), and location (Loc) of the well intersecting the cavity (i.e., on a ridge, hill, or valley). The north and east coordinates were not normalized relative to geologic strike because because the Y-12 east-west coordinate is approximately parallel to strike.

GLM modeling procedures were first attempted. GLM uses use linear least squares methods to fit a selected model that describes the relationship between one dependent variable (Size), and one or more explanatory or predictor variable(s). The GLM procedure allows for the explanatory variables to be both continuous numeric variables and class variables which have one or more discrete levels. In the case of the models described here, a class variable was used to describe location of monitoring wells. Wells are located on either ridge tops (R), sloping portions of hills (H), or valleys (V); hence the class variable location (Loc) has three levels. The complete model includes first and second order (polynomial effects) terms, as well as crossed effects for the continuous variables East, North, Elev, and Type (type of water interval which is either a cavity, fracture or slow-flow water interval). Crossed effects refer to terms composed of two variable multiplied by one another and by a coefficient (eg. Coefficient × Elev × East). In addition, main effects for the class variable (Loc), as well as interactions of this variable with the continuous variables are included in the model. The presence of the interaction terms allows for differences in the effect of the continuous explanatory variables on the dependent variable at the different locations.

Non-cavities (slowly flowing water intervals, or fractures) were assigned "0" size and the actual size of the cavity noted during drilling was used for the cavities. Different models were constructed using either the raw data (East and North in ft, Elev in ft above mean sea level (amsl), Size in ft), or transformed data (East and North in km, log(Elev), log(Size +1)).

Logistic Model

The LOG model procedure used in this work employs the method of maximum likelihood to fit linear logistic regression models to binary response data. The logistic regression analysis is used to evaluate the relationship between the probability of cavity occurrence and the explanatory variables used in this work (ie. East, North, etc.). The response variable (probability of cavity presence, p) is assumed to be related to the explanatory variables through the logit function given by

$$\text{logit}(p) = \ln\left(\frac{P}{1+P}\right) = \beta_0 + \beta_1 x_1 + \ldots + \beta_p x_p \qquad (1)$$

where x_1, ..., x_p represent the linear and quadratic terms for the continuous explanatory variables as well as the main effects and interactions of the class variable with the continuous variables. The β's are coefficients to be estimated from the observed data. The size variable was no longer included in the model. A "1" was assigned to slow flowing water intervals (non-cavities) and a "0" was assigned to cavities in an effort to predict the probability of the presence of cavities in specific locations.

Logistic models were run for both the Ccr and Cmn data sets using an extended model as described in equation (1). After formulating several LOG models using the same data set as was utilized in the GLM modeling, an additional attempt to use a LOG model to estimate the probability of conduit presence in specific locations was made by deleting all data from wells drilled prior to 1987 (well numbers less than GW-500). During recent plugging and abandonment activities at the Y-12 Plant, the available data from several of the older wells has been found to be faulty. The locations and total depths of wells were apparently reported incorrectly following well completion at a number of sites (W.K. Jago, pers. comm, 5/93). Hence, the reliability of recorded well completion information from wells drilled prior to 1987 is questionable. The reduced data set formed by deleting pre-1987 well data in the Cmn includes 185 water intervals, in 45 separate wells, of which 45 are cavities.

RESULTS

General Linear Model

Several models were constructed using both the raw data (East and North in feet, Elev in feet above mean sea level, Size in feet) and transformed data (East and North in km, log(Elev), log(Size +1)). Only selected models are discussed here, and Appendices B and C list summary results from these selected models. An "X" in a column in Appendix B indicates that the particular variable was utilized in the given model. Columns with an "*" between two variables (ie. East*Loc) indicate that the cross product between the two variables (East and Loc) was incorporated into the model.

Results from Cmn, Ccr and both data sets were compared between models that used Depth and those which used Elev instead of the Depth variable. R^2 values were similar when either Depth or Elev was used. The use of either Depth or Elev for the Z coordinate had negligible effect on the calculated R^2 values, which is not surprising given that the two are linearly related.

In some cases, slightly better squared multiple correlation coefficient (R^2) values were obtained with the transformed variables. However, other models have poorer R^2 values using the transformed data (compare file Ccr-2 to Ccr-6, Appendix B) indicating that these simple transformations can not be used to improve results appreciably. Since the R^2 values for Ccr-2 and Ccr-6 are calculated in different spaces (i.e., transformed versus untransformed), the differences in R^2 values may not be significant.

Much poorer results were obtained with the Cmn data set where R^2 values are all less than 0.40 (Appendix B). Models using all wells in the Ccr and Cmn together also had poor R^2 values, similar to models run using only the Cmn water intervals. The Cmn results were consistently worse than analyses using only the Ccr intervals (Appendices B and C). The fact that the Ccr and Cmn data sets have distinctly different R^2 values is not surprising considering the hydrogeology of the two differs. Flow in the Cmn is generally at elevations between 600 and 950 ft and is dominantly strike parallel through submerged, partially mud filled cavities with sizes up to 40 ft in vertical dimensions, but more typically less than 5 ft. The flow in the Ccr is generally above an elevation of 950 ft with flow both parallel and perpendicular to geologic strike through conduits which tend to be larger, and are often not fully saturated at the shallower depths.

Most analyses were, hence, conducted separately on the Cmn intervals and the Ccr intervals, and poor correlations were seen in all cases (Appendices B and C). In an attempt to improve predictions, another variable was introduced: the top of the water interval depth below the Ccr/Cmn contact (DBC). However, this data set was much smaller because the Cmn/Ccr contact is only encountered in a small number of wells. The Ccr data set decreased from 290 to 39 (R^2 increased from about 0.4 to 0.83), and the Cmn data set decreased from 390 to 133 (R^2 increased from about 0.31 to 0.33).

To determine if these smaller data sets were representative, the same models were run by simply removing the DBC variable to identify if this variable is important. Removing DBC from these new, smaller data files had no effect on the R^2 suggesting that the introduction of a new variable was not responsible for the better predictive capability of the model (see Appendix C; compare Cmn-5 with Cmn-5a, and Ccr-14 with Ccr-15). When an identical model is run using the larger data set (ie. compare Ccr-16 with Ccr-15 Appendix C), the R^2 value is much worse with the larger data set ($R^2 = 0.11$ for the 289 observation data set). The smaller subsets are apparently not representative subsets of the larger data sets and can not be used to make general statements about the larger data sets. For example, the Ccr range in the North variable is about 3400 ft smaller in the subset than in the larger data file. In the case of the smaller Cmn data set, the Elev variable covered a smaller range (315 ft less), and the North and East variables had a smaller range by ≈1200 and 32,000 ft, respectively, than did the complete data set (see Table 4). The best R^2 values were obtained from the subset which is not representative of the data set as a whole. The predictive capabilities of the GLM models were, hence, not suitable for the data set being modeled.

In the 39 observation Ccr subset, East, Loc and East*Loc were usually the dominant variables (smallest P values in Appendix C, file Ccr-14), whereas North was of importance in the larger data set (Ccr-16). Elev and East*Loc were the dominant variables in the 133 observation subset of Cmn (Cmn-13, Appendix C). Elev, Elev*Elev, N*Elev, and North*North were dominant in the complete data set (cmn-all, Appendix C). Note that in the Cmn-5a model (Appendix C), Loc, East, North, Elev and East*Loc were the only variables used in the 133 observation data set, and all were important; however, the model resulted in a low R^2 value of 0.308. Note that the crossed effect North*Elev was not found to be significant in the models. This crossed effect could provide an indirect indication of the influence of the lithology in particular Cmn zones, because individual Cmn zones occur nearly continuously along constant North values in the east-west direction, and at the same elevation in an east-west direction. Hence, the particular variables, and their crossed effects, in these models can not explain all of the variability in the data set. No other variables are available for inclusion into the model because none have been measured in relation to water intervals in a sufficient number of the wells.

Logistic Model

Following failure to identify general linear models capable of explaining a large percentage of the variability in the observed cavity size in the data sets, an alternative approach using logistic regression models was investigated. A "0" was assigned to cavities and a "1" was assigned to water intervals (non-cavities). Initially, an expanded model incorporating all terms and cross products was constructed. Appendix D lists selected model results along with P-values, parameter estimates (Param), and standard errors (Std. Err.) for the terms included in each model. The % Correct column lists the percentage of known cavities which were predicted correctly in the models and sample size lists the number of water intervals (observations) included in the models.

An influence option was used in the SAS Logistic procedure (SAS, 1990) to flag influential, individual observations based on the diagnostics developed by Pregibon (1981). For instance, in the cmn9 file, eight water intervals were identified as influential: BC-49 (805.2 ft), GW-214 (518.78, 612.78, 594.78 ft), GW-646 (934.01 ft), GW-712 (426.11), GW-713 (714.83), and GW-727 (792.96 ft), where elevations of the water intervals are noted in parentheses. It is not clear why these individual observations are more influential than others in the data set.

A model similar to that in cmn9 was run (cmn10) using the stepwise selection option with a value of 0.15 being used to specify the significance level for entry into, and exclusion from, the model. The percent correctly predicted by the model was 69.8% (Appendix D) and only the following variables were found to be significant in the model: location, N, N x N (North*North), and Elv x Elv (Elev*Elev). The same variables were found to be significant using significance levels for entry and exclusion from the model of up to 0.5, suggesting all other variables do not contribute appreciably to the explanation of the variability in the data set. Hence, the probability of cavity presence is not a strong function of the east coordinate location for this data set. Similar probabilities of cavity occurrence in the Cmn would be expected to be predicted regardless of the east location of the coordinate.

LOG models were also run on the Ccr data set using the stepwise variable selection option. The following variables were found to be the most important in the model: Elev, D2 x Elev (which is a location variable times the water interval elevation). This result was obtained for entry significance levels of 0.05 to 0.5, suggesting all other variables do not contribute significantly to the explanation of the variability in the data set.

Table 4. Ranges in values of variables used in the model runs incorporating the DBC variable.

	Ccr-all (289 values)		Ccr-small (39 values)		Cmn-all (390 values)		Cmn-small (133 values)	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Elevation (ft)	428	1,098	428	959	0	1,017	252	954
Depth (ft)	5	479.7	13	479.7	4	650	5	650
North (ft)	24,225	29,027	27,654	29,027	27,644	30,393	27,873	29,405
East (ft)	36,434	65,057	36,434	65,057	9088	69,712	36,434	65,057
Ranges:								
Elevation (ft)		670		531		1017.2		702
Depth (ft)		474.7		466.7		646		645
North (ft)		4,802		1,373		2,749		1,532
East (ft)		28,623		28,623		60,624		28,623
Differences:								
Elevation (ft)			139	79%			315.2	69%
Depth (ft)			8	98%			1	100%
North (ft)			3,429	29%			1,217	56%
East (ft)			0	100%			32,001	47%

The influence option was utilized in several models and several water intervals (observations) were flagged as being influential in the results. Even though there was no physical reason to suspect the data from these intervals were in error, all were deleted from their respective files, and the models re-run. Negligible differences in results were observed following deletion of these intervals (ie. compare ccr1a-all with ccr3a-all, and cmn3a-all with cmn6a-all in Appendix D).

The N-S range of values for the Cmn is 2749 ft, whereas the E-W extent of the data covers a length of 60,624 ft (Table 4). Because the 3-D data set is long and narrow, the estimated logistic function may not be numerically stable. Because the N-S dimensions of the Cmn study area are much less than the E-W dimensions, the study area was split into six segments in which the E-W dimensions were reduced to only two times the N-S dimensions. Models containing the same variables as cmn9 were run using the stepwise select option with entry significance levels of 0.15 (see Table 5 for results). Although variables involving Elev are important in four of the six subsets, it is clear that different variables are important in different portions of Bear Creek Valley.

As noted in the Procedures section, the final analysis involved deleting all data from wells drilled prior to 1987. Depth, rather than Elev, was used as a variable. Initial attempts to normalize the data by subtracting the mean from the variable value and dividing by the standard deviation did not yield appreciably improved model results. Hence, all variable values were divided by the mean value of that variable in order to normalize the data, and results improved. The percent of known cavities whose locations were predicted correctly is 81.1%, with a 36.1% and 14.8% false positive and false negative rate, respectively (cmn2a, Appendix D). Of the 45 known cavities in the data set, only 15 were predicted to have a ≥70% probably of occurrence. Nevertheless, the model was used in an attempt to predict the locations of cavities in the Cmn and evaluate how the model would behave in different portions of the aquifer.

The best LOG model was identified (cmn2a, Appendix D), and gridded data sets were constructed in order to be inserted into the model and used to predict the probability of cavity occurrence at specific locations. A 10-ft grid was utilized for both the Depth and North parameters, whereas a 100-ft grid was used for the East coordinate because previous analyses indicated the model was relatively insensitive to this variable. Only those locations in which a >70% probability of cavity occurrence were predicted were directed to an output file. This 70% limit was somewhat arbitrarily selected.

The model was used to predict the probability of cavity occurrence from gridded data sets in the vicinity of Picket W (E-W grid extent = 2500 ft), Picket A (E-W grid extent = 3200 ft), and Picket J (E-W grid extent = 2800 ft; see Figs. 1 and 2 for locations of pickets). Table 6 summarizes the results and shows that 10.5 to 15.4% of gridded points in Picket J were predicted to be locations of cavities when screened for probabilities of ≥70%. No cavities were predicted at Picket A, whereas cavities were predicted in about 6% of all gridded points at Picket W. Given that more cavities occur the Cmn in the Picket J vicinity than in the Picket W area, the results seem to reasonably reflect the field data. However, no cavities were predicted at Picket A, yet five cavities in two wells were encountered during drilling at the Picket A site (Jones et al., 1992). In addition, there is known hydraulic communication between conduits in one well (GW-684) and a local spring (Shevenell, et al., 1992) suggesting that this is an area of active conduit flow. A serious gap in prediction of cavity occurrence is located along a 3200 ft distance near Picket A, and this is completely unrealistic given that cavities are know to occur in this area.

DISCUSSION

Although the best identified LOG model does not reliably predict the probability of cavities being located in particular positions, it is successful in predicting the general configuration of cavity occurrence. Examination of results of the models at Pickets J and W, reveals that a cavity is very frequently predicted to occur at the shallowest grid points. No cavities were predicted at depths greater than 85 ft. Often, when a cavity was predicted at one shallow (e.g. 5 ft.) grid in a particular East and North location, cavities would also be predicted at the subsequent vertical grid points (i.e., at 5, 15, 25, 35, and 45 ft). The model predicts a high probability of cavity occurrence at shallow (<100 ft) depths, and this is recognized based

Table 5. Summary of results of reduced data sets in the Cmn with the use of transformed variables. The files are subsets of Cmn9 (incomplete observations were deleted).

File	East Range (ft)	Important Variables*	Correct	Number of Observations
e-spli1	36,000 to 41,687	ElevxElev	69.20%	52
e-spli2	41,688 to 47,237	ExElev	79.10%	43
e-spli3	47,238 to 52,856	ExN, ExDum1, NxElev	80.40%	107
e-spli4	52,857 to 58,475	ExN	75.00%	72
e-spli5	58,476 to 64,093	++	53.80%	39
e-spli6	64,094 to 69,712	ElevxElev	85.40%	41
			Ave = 73.8%	

* All subsets included the Intercept.
++ Modeling terminated following estimation of the Intercept.

Table 6. Number of cavities predicted in the Cmn at a >70% probability of occurrence at Pickets J, A, and W.

East Coordinate	# of Cav. Predicted	Total # of Grid Points	% of total >70% Prob	# of Wells	# of Water Zones	% of Zones = Cavities	Water Zones per Well
Picket J							
63000 - 63100	215	2,052	10.5%	5	33	48.5%	6.6
63200 - 63500	457	4,108	11.1%				
63600 - 63900	492	4,108	12.0%				
64000 - 64300	519	4,108	12.6%				
64400 - 64700	559	4,108	13.6%				
64800 - 65100	591	4,108	14.4%				
65500 - 65800	633	4,108	15.4%				
Total	*3,466*	*26,700*	*13.0%*				
Picket A							
39000 - 39100	0	3,508	0.0%	3	7	42.9%	2.3
41100 - 41200	0	3,508	0.0%				
41300 - 41400	0	3,508	0.0%				
41500 - 41600	0	3,508	0.0%				
41700 - 41800	0	3,508	0.0%				
41900 - 42000	0	3,508	0.0%				
42100 - 42200	0	3,508	0.0%				
Total	*0*	*24,556*	*0.0%*				
Picket W							
36300 - 36400	275	4,447	6.2%	5	28	21.4%	5.6
36500 - 36600	276	4,447	6.2%				
36700 - 36800	276	4,447	6.2%				
36900 - 37000	275	4,447	6.2%				
37100 - 37200	277	4,447	6.2%				
37300 - 37400	282	4,447	6.3%				
37500 - 37600	281	4,447	6.3%				
37700 - 37800	282	4,447	6.3%				
37900 - 38000	282	4,447	6.3%				
38100 - 38200	285	4,447	6.4%				
38300 - 38400	288	4,447	6.5%				
38500 - 38600	288	4,447	6.5%				
38700 - 38800	290	4,447	6.5%				
Total	*3,657*	*57,811*	6.3%				

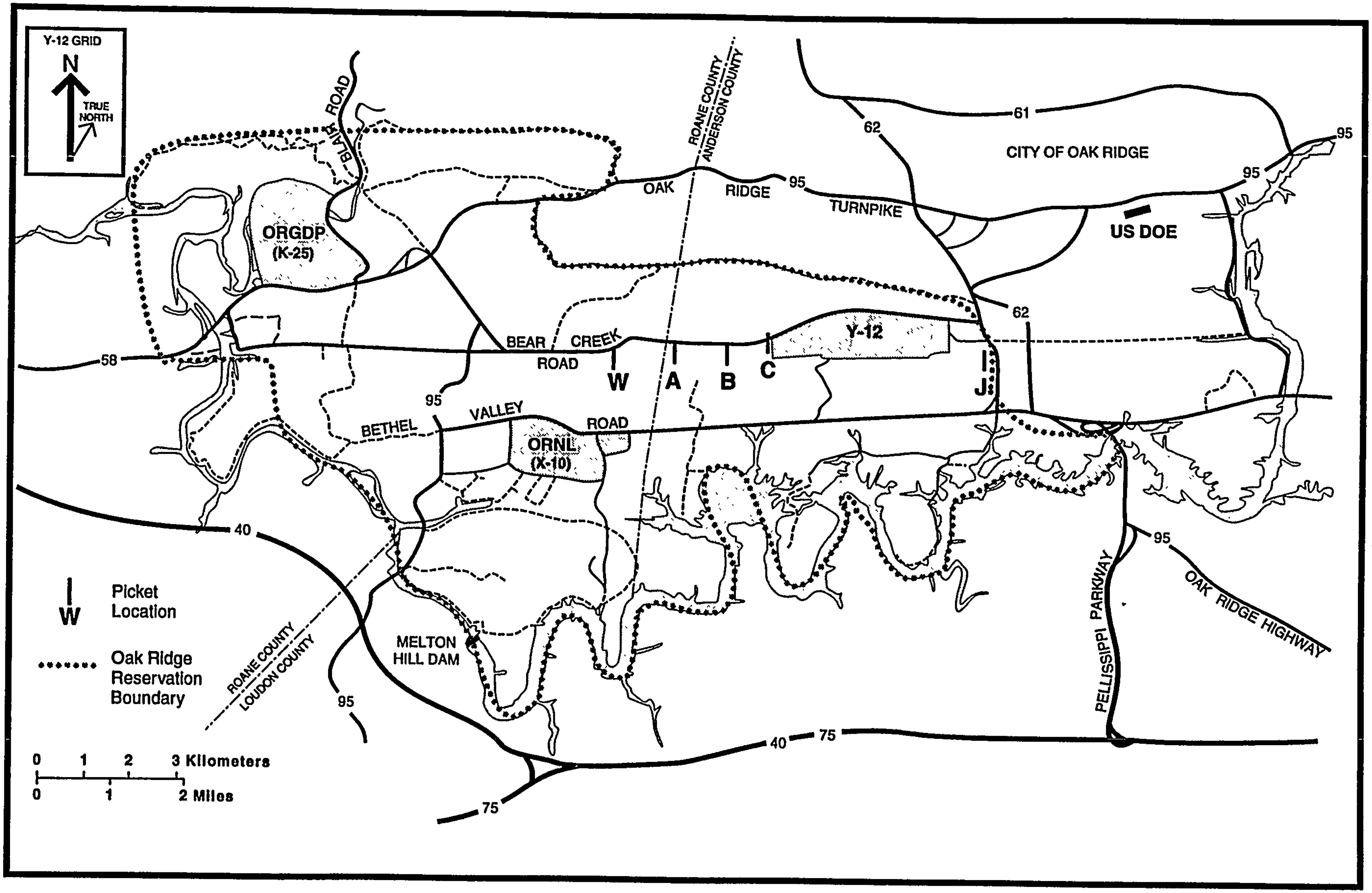

Figure 2. General locations of the Cmn Pickets at the Y-12 Plant.

on drilling data.

Table 7 shows the total number of water intervals (observations) encountered in each of several depth intervals in the Ccr and Cmn for both the full data set, and reduced data set (wells newer than GW-500 are identified by 'Wells >GW-500'). Note that fractures were identified during drilling by increases in water production accompanied by rig chatter, or by visible alteration on the cuttings surfaces. Using the information in this table, the data show that for the reduced Cmn data set, 45.5% of all water intervals encountered at depths <100 ft have been cavities, whereas only 10.5% of the water intervals have been cavities at depths >100 ft. The percentage of cavities at shallow depths is even larger for the full data set with 55.8% of water intervals being cavities at depths <100 ft, and 12.9% being cavities at depths >100 ft. The data are biased in this manner because most wells are drilled to depths <100 ft. However, it is believed that cavities are more likely to occur at shallower depths. For instance, if a small data set is taken from Shevenell et al. (1992) and evaluated based on elevation (where higher elevations correspond to shallower depths, and vice versa) one sees a distinct lack of cavities below 600 ft elevation (Table 8). Between elevations of ≈0 and 700 ft, fracture frequency tends to increase with increasing elevation from 5.3% of all water intervals to 20% of all water intervals, likely due to decreasing load on the fractures and a greater tendency for them to be open at shallower depths. At elevations greater than 700 ft, fracture frequency decreases while cavity frequencies increase from, 3.3 to 10% of all water intervals. This suggests that fractures are more likely to be enlarged through dissolution at higher elevations, and hence, shallower depths. The LOG model described was successful at duplicating this feature of the karst aquifer system.

The LOG model was also successful at representing conduits in the east-west direction. The model was insensitive to the East coordinate location which indicates this variable is not important in predicting the occurrence of cavities in the Cmn. Given that groundwater flow in the Cmn predominantly occurs along strike through presumably interconnected conduits and fractures, the LOG model reflects reality as it will predict cavity occurrence at a particular depth and north location with little dependence on the East location in the valley.

Each of the models attempted were very sensitive to the data set used. Subsets of the full data set could not be used to predict the behavior of the larger data set and the Cmn and Ccr data sets differ significantly. There are two obvious reasons why this would be the case: (1) the larger and smaller data sets do not exhibit the same percentage of cavities per well per depth range (Table 9), and (2) hydrologic characteristics are not homogeneous throughout the formations, as is known to be the case in the Cmn (Table 9; and see Shevenell et al., 1992). Regarding the first reason, Table 9 lists the number of cavities, fractures and water intervals per well by depth. The data in Table 9 show that the distribution of the water intervals differs between the larger and reduced data set. For instance, in the Ccr data, 0.79 fractures per well are noted for wells drilled to depths >250 ft in the full data set, whereas only 0.29 fractures per well are noted in the reduced data set. Similarly, in the Cmn data, the number of cavities per well in the larger data set in depth intervals of 0 to 25 ft, 25 to 50 ft, and 50 to 75 ft is 0.40, 0.52 and 0.28, respectively. The corresponding numbers in the reduced (>GW-500) data set are 0.07, 0.40 and 0.53, respectively. One would not expect a similar model result to be obtained from both data sets. Also see Table 4 which lists the different ranges of values for each of the two data sets.

Listings in Table 9 also illustrate that hydrologic characteristics (ie. presence of cavities) are not consistent as a function of depth, nor between the Cmn and Ccr. More cavities occur at shallow depths (<75 ft) and more fractures occur at deeper levels (>100 ft) in the Cmn, and similarly, the Cmn tends to have more cavities per well at shallow (<75 ft) depths than does the Ccr. The fact that cavities tend to occur at the shallower depths is reasonable given that waters flowing to the deeper levels will likely have become saturated with respect to calcite, thus dissolution is much less likely at deeper levels (i.e., further along the flow path).

More detailed data are available from the Cmn than the Ccr, and these data also show distinct variability in cavity occurrence as a function of the lithologic zone within the Cmn (Table 10). Four of the five zones contain a large percentage of the cavities, whereas no cavities have been noted in zone 3. Note

Table 7. Waters zones encountered in the Ccr and Cmn by depth in both the full and reduced data sets.

	Number of Water Zones Encountered			Total #	% Water	Percent of Total Water Zones by Depth		
Water Depth	Cavity	Fracture	Water	Water Zones	by Depth	Cavity	Fracture	Water
Ccr - All Wells								
0 to 25 ft	7	9	4	20	6.7%	35.0%	45.0%	20.0%
25 to 50	17	4	1	22	7.4%	77.3%	18.2%	4.5%
50 to 75	26	11	10	47	15.7%	55.3%	23.4%	21.3%
75 to 100	29	18	7	54	18.1%	53.7%	33.3%	13.0%
100 to 125	22	21	16	59	19.7%	37.3%	35.6%	27.1%
125 to 150	12	19	2	33	11.0%	36.4%	57.6%	6.1%
150 to 200	7	18	10	35	11.7%	20.0%	51.4%	28.6%
200 to 250	3	5	1	9	3.0%	33.3%	55.6%	11.1%
250 to ...	1	11	8	20	6.7%	5.0%	55.0%	40.0%
Total				299		41.5%	38.8%	19.7%

Max Depth Cavity: 314 ft
Max Depth Fracture: 362 ft
Max Depth Water: 479.4

	Number of Water Zones Encountered			Total #	% Water	Percent of Total Water Zones by Depth		
Water Depth	Cavity	Fracture	Water	Water Zones	by Depth	Cavity	Fracture	Water
Ccr - Wells >GW-500								
0 to 25 ft	6	0	4	10	7.8%	60.0%	0.0%	40.0%
25 to 50	14	0	1	15	11.6%	93.3%	0.0%	6.7%
50 to 75	12	5	9	26	20.2%	46.2%	19.2%	34.6%
75 to 100	9	3	7	19	14.7%	47.4%	15.8%	36.8%
100 to 125	11	1	12	24	18.6%	45.8%	4.2%	50.0%
125 to 150	5	1	1	7	5.4%	71.4%	14.3%	14.3%
150 to 200	5	3	8	16	12.4%	31.3%	18.8%	50.0%
200 to 250	2	0	1	3	2.3%	66.7%	0.0%	33.3%
250 to ...	0	4	5	9	7.0%	0.0%	44.4%	55.6%
Total				129		49.6%	13.2%	37.2%

Max Depth Cavity: 216 ft
Max Depth Fracture: 350 ft
Max Depth Water: 479.4

Table 7 (Continued)

Water Depth	Number of Water Zones Encountered			Total #	% Water	Percent of Total Water Zones by Depth		
	Cavity	Fracture	Water	Water Zones	by Depth	Cavity	Fracture	Water
Cmn - All Wells								
0 to 25 ft	51	9	18	78	20.4%	65.4%	11.5%	23.1%
25 to 50	62	22	19	103	26.9%	60.2%	21.4%	18.4%
50 to 75	22	13	13	48	12.5%	45.8%	27.1%	27.1%
75 to 100	5	9	8	22	5.7%	22.7%	40.9%	36.4%
100 to 125	5	13	9	27	7.0%	18.5%	48.1%	33.3%
125 to 150	1	10	11	22	5.7%	4.5%	45.5%	50.0%
150 to 200	2	15	16	33	8.6%	6.1%	45.5%	48.5%
200 to 250	4	12	6	22	5.7%	18.2%	54.5%	27.3%
250 to ...	0	13	15	28	7.3%	0.0%	46.4%	53.6%
Total				383		39.7%	30.3%	30.0%

Max Depth Cavity: 236.5 ft
Max Depth Fracture: 490 ft
Max Depth Water: 650 ft

Water Depth	Number of Water Zones Encountered			Total #	% Water	Percent of Total Water Zones by Depth		
	Cavity	Fracture	Water	Water Zones	by Depth	Cavity	Fracture	Water
Cmn - Wells > GW-500								
0 to 25 ft	3	2	10	15	7.7%	20.0%	13.3%	66.7%
25 to 50	17	4	8	29	14.9%	58.6%	13.8%	27.6%
50 to 75	17	4	11	32	16.4%	53.1%	12.5%	34.4%
75 to 100	4	3	7	14	7.2%	28.6%	21.4%	50.0%
100 to 125	2	7	8	17	8.7%	11.8%	41.2%	47.1%
125 to 150	0	5	8	13	6.7%	0.0%	38.5%	61.5%
150 to 200	2	13	14	29	14.9%	6.9%	44.8%	48.3%
200 to 250	3	12	5	20	10.3%	15.0%	60.0%	25.0%
250 to ...	0	13	13	26	13.3%	0.0%	50.0%	50.0%
Total				195		24.6%	32.3%	43.1%

Max Depth Cavity: 236.5 ft
Max Depth Fracture: 490 ft
Max Depth Water: 650 ft

Table 8. Summary of water breaks by elevation above MSL (based on data from Cmn Picket wells in Shevenell et al., 1992).

	Elevation 0 ft to 500 ft	Elevation 500 ft to 600 ft	Elevation 600 ft to 700 ft	Elevation 700 ft to 800 ft	Elevation 800 ft to 900 ft	Elevation 900 ft to 1000 ft
Wells Drilled*	4	6	8	15	28	19
Total Number of Fractures	1	2	5	6	7	3
Total Number of Cavities	0	0	1	2	11	5
Total of All Water Zones	19	15	25	60	137	50
% of Total Zones that are Fractures	5.3%	13.3%	20.0%	10.0%	5.1%	6.0%
% of Total Zones that are Cavities	0.0%	0.0%	4.0%	3.3%	8.0%	10.0%

* The total number of wells which penetrate any portion of the elevation interval.

Table 9. Summary of water zones by well and depth in the Ccr and Cmn.

Total Depth	# of Wells *	# of Wells +	# Wells > GW-500*	# Wells > GW-500+	Water Zones per Well - All Wells Cavity	Fracture	Water	Water Zones per Well - Wells >GW-500 Cavity	Fracture	Water
Ccr										
0 to 25 ft	2	99	2	55	0.07	0.09	0.04	0.11	0.00	0.07
25 to 50	2	97	1	53	0.18	0.04	0.01	0.26	0.00	0.02
50 to 75	2	95	1	52	0.27	0.12	0.11	0.23	0.10	0.17
75 to 100	10	93	10	51	0.31	0.19	0.08	0.18	0.06	0.14
100 to 125	11	83	5	41	0.27	0.25	0.19	0.27	0.02	0.29
125 to 150	18	72	6	36	0.17	0.26	0.03	0.14	0.03	0.03
150 to 200	30	54	13	30	0.13	0.33	0.19	0.17	0.10	0.27
200 to 250	5	24	3	17	0.13	0.21	0.04	0.12	0.00	0.06
250 to ...	19	19	14	14	0.05	0.79	0.42	0.00	0.29	0.36
Total > 100 ft	83		41							
Total % > 100 ft	83.8%		74.5%							
Total < 100 ft	16		14							
Total % < 100 ft	16.2%		25.5%							

Maximum Depth Drilled = 744.5 ft

Total Depth	# of Wells *	# of Wells +	# Wells > GW-500*	# Wells > GW-500+	Water Zones per Well - All Wells Cavity	Fracture	Water	Water Zones per Well - Wells >GW-500 Cavity	Fracture	Water
Cmn										
0 to 25 ft	8	127	2	44	0.40	0.07	0.14	0.07	0.05	0.23
25 to 50	39	119	10	42	0.52	0.18	0.16	0.40	0.10	0.19
50 to 75	18	80	5	32	0.28	0.16	0.16	0.53	0.13	0.34
75 to 100	13	62	4	27	0.08	0.15	0.13	0.15	0.11	0.26
100 to 125	8	49	3	23	0.10	0.27	0.18	0.09	0.30	0.35
125 to 150	11	41	4	20	0.02	0.24	0.27	0.00	0.25	0.40
150 to 200	9	30	4	16	0.07	0.50	0.53	0.13	0.81	0.88
200 to 250	2	21	1	12	0.19	0.57	0.29	0.25	1.00	0.42
250 to ...	19	19	11	11	0.00	0.68	0.79	0.00	1.18	1.18
Total > 100 ft	49		23							
Total % > 100 ft	38.6%		52.3%							
Total < 100 ft	78		21							
Total % < 100 ft	61.4%		47.7%							

Maximum Depth Drilled = 666.2 ft

* the total number of wells completed in the particular depth interval
\+ the total number of wells which penetrated the particular depth interval.

Table 10. Occurrence of cavities in the Cmn.

Zone	# of Wells	% of Wells with Cavities	% Water Zones that are Cavities
Cmn-6	12	41	19
Cmn-5	13	23	17
Cmn-4	8	12.5	25
Cmn-3	6	0	0
Cmn-2	10	20	38

Note: Data are based on data in Shevenell et al. (1992)

that the data in Table 10 are not directly a function of depth because the Cmn dips at an average angle of 45°. Also, see Tables 4, 7 and 8 for differences in data as a function of east-west location, depth and elevation.

The geologic variables which will likely give the best predictive capability were not investigated as part of this study. For instance, there is lithologic and thickness variability between the different zones within the Cmn (Shevenell et al., 1992; Goldstrand, in press), yet these data are only available for a very limited number of wells. If there were more consistent data on grain size, fracture frequency, secondary porosity development, lithologic and mineralogic variability, and variations in zone thicknesses for the separate Cmn zones throughout BCV, these types of data could be incorporated into a statistical model. This additional information would likely be useful in better constraining the occurrence and distribution of conduit locations in the Cmn.

The locations of cavities are likely to be related to several other interacting variables. The following factors are believed to be important in cavity occurrence: (1) location relative to the Cmn subcrop, (2) location relative to major springs, sinkholes and faults and fractures, (3) location relative to cross cutting valleys (strike perpendicular valleys). Data for item (2) is unknown in many cases (ie. faults and fractures) when referring to these characteristics in relation to particular water zones encountered at depth, and would be of little use in GLM and LOG models. However, the locations of springs, sinkholes, and cross cutting valleys are relatively well known, and the distance and bearing of known conduits to these features could be incorporated into LOG and GLM type models. Perhaps the addition of these types of data would improve the results of a LOG or GLM model. These data could also be used to qualitatively estimate cavity location.

CONCLUSIONS AND RECOMMENDATIONS

The General Linear Models and Logistic Regression Models formulated were not successful in adequately predicting cavity size or the probability of cavity occurrence at specific locations within the Ccr and Cmn. In the LOG models, the East and North coordinates were not significant variables in the Ccr data, and the East coordinate was not a significant variable in the Cmn data set. Hence, with a given Elev, Loc, and North value, cavity presence would be independent of the East value in the Cmn. The model is insensitive to the east coordinate, which is reasonable given that the dominant flow direction in the Cmn is along strike (E-W). Both GLM and LOG analyses suggest that cavity size and presence in Cmn is a strong function of North and Elev (or Depth).

Models were constructed for all water intervals in both the Cmn and Ccr, and for each unit separately. The model results were consistently different between the Cmn and Ccr. The fact that the Ccr and Cmn data sets appear to produce different models is not surprising considering the hydrogeology of the two differs. Flow in the Cmn is generally at elevations between 600 and 950 ft and is dominantly strike parallel through submerged, partially mud-filled cavities with sizes up to 40 ft in diameter, but more typically less than 5 ft. Recognized flow in the Ccr is generally above an elevation of 950 ft with flow both parallel and perpendicular to geologic strike through conduits which tend to be larger, and are often not fully saturated at the shallower depths.

A subset of the full data set which included the depth below lithologic contact (DBC) variable was used some estimation procedures. In the 39 observation Ccr data subset including DBC, East, Loc and East*Loc were usually the dominant variables, whereas North was also of importance in the larger data set. Elev and East*Loc were the dominant variables in the 133 observation subset of Cmn data. Elev, Elev*Elev, N*Elev, and north*north were dominant in the complete data set. Numerous differences between the data sets occur and it is clear that the smaller data sets are not representative subsets of the full data set.

All available spatial data were used to construct logistic regression models, and a secondary data set, which was much smaller and eliminated questionable data collected prior to 1987, was used in an attempt to find a suitable model. An insufficient number of variables were found to be important in explaining the observed variability in the data sets in both the Ccr and Cmn. For instance, the resulting model for Cmn is not a strong function of East coordinates, and the Ccr model is not a strong function of either the North or East coordinates. Hence, the presence or absence of a cavity at a given location can not be predicted because not all variables that define a point in space are significant. Given the complexities of the karst aquifers and limited resources available to fully identify cavity locations and characterize relevant hydrologic and geologic parameters, it is possible that logistic and GLM models will be inadequate in predicting cavity occurrence based on the variables used in the current models regardless of the amount of additional data that may be acquired from drilling. Perhaps some of the information presented in this report could be incorporated into 2-D or 3-D probability plots which may provide some insight into future modeling efforts.

Although the models were unsuccessful in providing a means of adequately predicting the cavity size or probability of cavity occurrence in the Ccr and Cmn, ongoing work in the Cmn may provide additional information which can be incorporated into future models. Variables such as lithology, stratigraphy, mineralogy, and bed thicknesses could have been very useful in constraining the models, yet detailed geologic information is not available at most well locations. Intervals of quick flow through the Ccr and Cmn have been identified with the use of geochemical data (Shevenell, in press) and this information could be used to condition the existing cavity location data. Cross borehole testing and long-term water level, temperature and specific conductance monitoring are providing data to evaluate directional characteristics of hydraulically active conduits, and response times to precipitation events in several locations throughout the study area. The hydrologic characteristics of the conduits may be useful in constructing more representative models by using this information to condition and weight the location data.

Numerous other controlling variables were not included in the model due to lack of data at many of the locations. For instance, the presence or absence of a cavity is likely to be a function of lithology, zone thicknesses, and matrix and secondary porosity values, and such variables would give and indication of the ease of dissolution and likelihood of cavity occurrence. These types of data could be examined on localized areas where data are available, but were not considered in this report because these data are not known in detail at most well bore locations. Numerous studies show that zone 2 of the Cmn is very likely to contain cavities, particularly at shallow depths (Shevenell et al., 1992; Goldstrand, in press). Ongoing work on matrix and secondary porosity development in the Cmn and Ccr (Goldstrand, in press; Goldstrand et al. in prep) will provide additional information on the lithologic zones, and depth control on conduit development in this karst aquifer which will be useful in formulating future models. Goldstrand (in press) indicate that important controls on secondary porosity development are dissolution of gypsum, dedolomitization, carbonate grain-size (with finer grain sizes being subject to greater dissolution), and oxidation of pyrite. Simply location data are not sufficient to identify the probability of cavity occurrence. Hydrologic, geologic, and geochemical data and interpretations must be incorporated into future modeling efforts in order to obtain a better prediction of cavity location as a function of all relevant variables.

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APPENDICES

Appendix A. Listing of water zones in the Cmn and Ccr used in this report

Appendix B. Selected GLM model results for both transformed and non-transformed data.

Appendix C. Comparison of selected GLM model results with and without the use of the DBC variable.

Appendix D. Summary of selected logistic model results. Variables are transformed unless otherwise noted.

Appendix A: List of water zones in the Cmn and Ccr used in this report.

A zone type of 0 refers to fractures and water zones, and 1 refers to cavities. Location indicates the well location on a ridge (R), or hill (H), or in a valley (V). A "." entry indicates no data are available

Well Number	Type	Loc	Size (ft)	Easting (ft)	Northing (ft)	Depth Water (ft)	Elevation Water (ft)
Copper Ridge Dolomite							
1084	0	H	0.00	53599	25008	120.00	842.24
1085	1	H	5.00	52997	26097	86.00	944.73
1085	0	H	0.00	52997	26097	112.00	918.73
1086	1	H	2.00	52316	26923	99.00	993.10
1086	1	H	2.00	52316	26923	124.00	968.10
1086	0	H	0.00	52316	26923	140.00	952.10
1087	1	H	4.50	52289	25817	72.50	931.63
1087	0	H	0.00	52289	25817	130.00	874.13
GW-099	0	R	0.00	52074	28495	86.00	1092.67
GW-099	0	R	0.00	52074	28495	112.00	1066.67
GW-141	1	R	.	52463	28755	145.50	1037.95
GW-141	0	R	0.00	52463	28755	120.00	1063.45
GW-141	0	R	0.00	52463	28755	145.00	1038.45
GW-147	0	R	0.00	63428	24731	10.00	838.41
GW-147	0	R	0.00	63428	24731	19.00	829.41
GW-147	0	R	0.00	63428	24731	20.00	828.41
GW-147	0	R	0.00	63428	24731	24.00	824.41
GW-147	0	R	0.00	63428	24731	32.50	815.91
GW-147	0	R	0.00	63428	24731	46.50	801.91
GW-147	0	R	0.00	63428	24731	59.50	788.91
GW-155	0	R	0.00	64333	27722	130.00	928.88
GW-155	0	R	0.00	64333	27722	165.00	893.88
GW-156	1	R	1.00	64020	27626	92.00	954.94
GW-156	1	R	2.00	64020	27626	101.00	945.94
GW-156	1	R	6.00	64020	27626	106.00	940.94
GW-156	0	R	0.00	64020	27626	150.00	896.94
GW-157	0	R	0.00	63892	27477	74.00	970.85
GW-157	0	R	0.00	63892	27477	114.00	930.85
GW-157	0	R	0.00	63892	27477	140.00	904.85
GW-158	0	R	0.00	63643	27069	98.00	883.24
GW-158	0	R	0.00	63643	27069	180.00	801.24
GW-158	0	R	0.00	63643	27069	220.00	761.24
GW-158	0	R	0.00	63643	27069	250.00	731.24
GW-159	1	R	5.00	63496	27764	112.00	936.79
GW-159	0	R	0.00	63496	27764	130.00	918.79
GW-160	1	R	.	62165	27803	111.00	979.66
GW-160	1	R	3.00	62165	27803	115.00	975.66
GW-160	1	R	3.00	62165	27803	137.00	953.66
GW-160	1	R	2.00	62165	27803	169.00	921.66
GW-160	1	R	3.00	62165	27803	221.00	869.66
GW-160	0	R	0.00	62165	27803	112.00	978.66
GW-160	0	R	0.00	62165	27803	118.00	972.66
GW-160	0	R	0.00	62165	27803	160.00	930.66
GW-160	0	R	0.00	62165	27803	171.00	919.66
GW-161	0	R	0.00	62146	27805	98.00	992.91
GW-161	0	R	0.00	62146	27805	140.00	950.91
GW-161	0	R	0.00	62146	27805	170.00	920.91
GW-161	0	R	0.00	62146	27805	218.00	872.91
GW-161	0	R	0.00	62146	27805	236.00	854.91
GW-161	0	R	0.00	62146	27805	314.00	776.91
GW-161	0	R	0.00	62146	27805	362.00	728.91
GW-161	0	R	0.00	62146	27805	370.00	720.91
GW-165	1	R	10.00	44547	27807	103.00	987.39
GW-165	1	R	3.00	44547	27807	314.00	776.39

Well Number	Type	Loc	Size (ft)	Easting (ft)	Northing (ft)	Depth Water (ft)	Elevation Water (ft)
GW-165	0	R	0.00	44547	27807	92.00	998.39
GW-165	0	R	0.00	44547	27807	100.00	990.39
GW-165	0	R	0.00	44547	27807	312.00	778.39
GW-166	0	R	0.00	44531	27835	287.00	805.01
GW-166	0	R	0.00	44531	27835	320.00	772.01
GW-166	0	R	0.00	44531	27835	323.00	769.01
GW-173	1	R	.	59472	28271	108.90	1004.07
GW-173	1	R	1.00	59472	28271	140.00	972.97
GW-173	0	R	0.00	59472	28271	103.60	1009.37
GW-174	1	R	16.60	59215	28205	63.00	1051.06
GW-174	1	R	.	59215	28205	91.00	1023.06
GW-174	1	R	.	59215	28205	140.00	974.06
GW-174	0	R	0.00	59215	28205	143.00	971.06
GW-175	1	R	.	58686	28676	85.00	996.89
GW-175	0	R	0.00	58686	28676	125.00	956.89
GW-175	0	R	0.00	58686	28676	160.00	921.89
GW-175	0	R	0.00	58686	28676	161.00	920.89
GW-177	1	R	5.00	57497	28483	68.00	1087.52
GW-177	1	R	1.50	57497	28483	96.00	1059.52
GW-177	0	R	0.00	57497	28483	130.00	1025.52
GW-178	1	R	.	57808	28552	43.00	1098.06
GW-178	1	R	.	57808	28552	45.50	1095.56
GW-178	1	R	.	57808	28552	52.00	1089.06
GW-178	1	R	.	57808	28552	58.00	1083.06
GW-178	1	R	.	57808	28552	64.00	1077.06
GW-178	1	R	.	57808	28552	82.00	1059.06
GW-178	0	R	0.00	57808	28552	74.00	1067.06
GW-178	0	R	0.00	57808	28552	80.00	1061.06
GW-178	0	R	0.00	57808	28552	81.00	1060.06
GW-178	0	R	0.00	57808	28552	84.00	1057.06
GW-178	0	R	0.00	57808	28552	90.00	1051.06
GW-178	0	R	0.00	57808	28552	100.00	1041.06
GW-178	0	R	0.00	57808	28552	106.00	1035.06
GW-178	0	R	0.00	57808	28552	121.00	1020.06
GW-178	0	R	0.00	57808	28552	125.00	1016.06
GW-179	1	R	19.60	58569	28522	53.00	1071.33
GW-179	0	R	0.00	58569	28522	112.00	1012.33
GW-180	1	R	.	59220	28494	58.00	1043.43
GW-180	1	R	.	59220	28494	68.00	1033.43
GW-180	1	R	.	59220	28494	78.00	1023.43
GW-180	1	R	.	59220	28494	81.00	1020.43
GW-180	1	R	.	59220	28494	83.00	1018.43
GW-180	1	R	.	59220	28494	85.00	1016.43
GW-180	0	R	0.00	59220	28494	97.00	1004.43
GW-180	0	R	0.00	59220	28494	132.00	969.43
GW-181	1	R	2.00	57736	28048	147.00	943.55
GW-217	0	R	0.00	53020	28758	125.00	1049.29
GW-217	0	R	0.00	53020	28758	165.00	1009.29
GW-221	0	R	0.00	54389	28359	36.00	1067.36
GW-221	0	R	0.00	54389	28359	153.00	950.36
GW-231	0	H	0.00	63410	24725	15.00	831.90
GW-231	0	H	0.00	63410	24725	17.00	829.90
GW-231	0	H	0.00	63410	24725	19.00	827.90
GW-231	0	H	0.00	63410	24725	23.00	823.90
GW-231	0	H	0.00	63410	24725	25.00	821.90
GW-231	0	H	0.00	63410	24725	28.00	818.90
GW-233	1	R	.	52596	28415	130.00	1049.44
GW-233	0	R	0.00	52596	28415	127.00	1052.44
GW-233	0	R	0.00	52596	28415	134.00	1045.44
GW-233	0	R	0.00	52596	28415	154.50	1024.94
GW-233	0	R	0.00	52596	28415	149.00	1030.44
GW-233	0	R	0.00	52596	28415	167.00	1012.44

Well Number	Type	Loc	Size (ft)	Easting (ft)	Northing (ft)	Depth Water (ft)	Elevation Water (ft)
GW-241	1	R	11.00	63659	27069	78.00	902.80
GW-241	0	R	0.00	63659	27069	89.00	891.80
GW-292	1	H	1.50	62146	28141	56.50	1013.61
GW-292	1	H	2.50	62146	28141	93.00	977.11
GW-292	0	H	0.00	62146	28141	58.00	1012.11
GW-292	0	H	0.00	62146	28141	66.00	1004.11
GW-292	0	H	0.00	62146	28141	177.00	893.11
GW-293	1	R	3.00	62321	28112	107.00	954.70
GW-293	0	R	0.00	62321	28112	59.00	1002.70
GW-293	0	R	0.00	62321	28112	206.00	855.70
GW-294	0	R	0.00	62483	27958	62.00	1019.74
GW-295	1	R	2.01	62184	27802	137.00	953.42
GW-295	0	R	0.00	62184	27802	110.00	980.42
GW-295	0	R	0.00	62184	27802	115.00	975.42
GW-295	0	R	0.00	62184	27802	120.00	970.42
GW-295	0	R	0.00	62184	27802	135.00	955.42
GW-297	1	R	.	62057	27885	81.00	1017.88
GW-297	1	R	.	62057	27885	93.00	1005.88
GW-298	1	R	.	62445	27495	90.00	956.40
GW-298	0	R	0.00	62445	27495	179.00	867.40
GW-298	0	R	0.00	62445	27495	182.00	864.40
GW-299	0	R	0.00	62319	27392	132.00	919.33
GW-299	0	R	0.00	62319	27392	156.00	895.33
GW-300	0	R	0.00	62041	27487	141.00	929.69
GW-301	1	R	.	61964	27662	93.50	990.44
GW-301	1	R	15.00	61964	27662	121.00	962.94
GW-301	0	R	0.00	61964	27662	109.00	974.94
GW-301	0	R	0.00	61964	27662	118.00	965.94
GW-301	0	R	0.00	61964	27662	154.00	929.94
GW-302	1	R	3.00	54353	28694	70.00	1069.59
GW-302	1	R	2.00	54353	28694	86.00	1053.59
GW-302	0	R	0.00	54353	28694	127.00	1012.59
GW-302	0	R	0.00	54353	28694	131.00	1008.59
GW-302	0	R	0.00	54353	28694	99.80	1039.79
GW-303	1	R	.	63488	28099	39.00	965.44
GW-303	1	R	.	63488	28099	109.00	895.44
GW-303	0	R	0.00	63488	28099	258.00	746.44
GW-303	0	R	0.00	63488	28099	302.00	702.44
GW-303	0	R	0.00	63488	28099	310.00	694.44
GW-305	0	R	0.00	52962	28548	169.00	1012.07
GW-322	1	R	20.00	58912	28241	98.00	1033.81
GW-322	1	R	2.00	58912	28241	188.00	943.81
GW-322	0	R	0.00	58912	28241	83.00	1048.81
GW-322	0	R	0.00	58912	28241	125.00	1006.81
GW-323	0	R	0.00	52106	28965	97.00	1030.41
GW-323	0	R	0.00	52106	28965	100.50	1026.91
GW-323	0	R	0.00	52106	28965	106.50	1020.91
GW-339	1	R	.	54147	28659	54.00	1068.18
GW-339	1	R	.	54147	28659	67.00	1055.18
GW-339	1	R	.	54147	28659	82.00	1040.18
GW-339	0	R	0.00	54147	28659	107.00	1015.18
GW-511	1	R	2.00	57739	28056	85.00	1005.70
GW-511	1	R	.	57739	28056	152.00	938.70
GW-513	1	H	7.00	57332	27607	75.00	923.99
GW-513	1	H	5.00	57332	27607	92.00	906.99
GW-514	1	H	3.70	57341	27575	44.30	954.36
GW-514	1	H	12.00	57341	27575	78.00	920.66
GW-514	1	H	1.00	57341	27575	157.00	841.66
GW-521	1	R	2.00	52040	28541	127.00	1052.46
GW-522	1	R	2.00	52612	28377	102.00	1070.04
GW-522	1	R	.	52612	28377	116.00	1056.04
GW-539	0	H	0.00	52278	27193	11.00	1079.39

Well Number	Type	Loc	Size (ft)	Easting (ft)	Northing (ft)	Depth Water (ft)	Elevation Water (ft)
GW-539	0	H	0.00	52278	27193	155.00	935.39
GW-540	1	H	7.00	52371	27489	125.00	944.38
GW-540	1	H	4.00	52371	27489	139.00	930.38
GW-541	1	H	0.50	51738	27654	69.00	986.79
GW-542	0	H	0.00	51642	27466	73.00	976.03
GW-543	0	H	0.00	51458	27072	86.00	935.19
GW-544	0	H	0.00	51820	26963	104.00	938.53
GW-544	0	H	0.00	51820	26963	107.00	935.53
GW-545	0	H	0.00	51729	27641	55.00	1000.43
GW-545	0	H	0.00	51729	27641	59.00	996.43
GW-546	0	H	0.00	52366	27474	72.50	997.14
GW-546	0	H	0.00	52366	27474	82.50	987.14
GW-551	1	H	.	60263	27299	122.00	868.36
GW-551	1	H	22.40	60263	27299	122.60	867.76
GW-551	1	H	1.40	60263	27299	213.00	777.36
GW-554	1	H	0.90	61288	25356	102.60	804.20
GW-555	1	H	5.00	59851	25868	75.00	859.91
GW-558	1	H	.	58949	26104	50.00	931.41
GW-561	1	R	7.40	59323	27811	56.40	974.34
GW-607	0	R	0.00	58922	27866	143.00	929.86
GW-608	1	R	21.00	59724	27889	114.00	957.00
GW-608	1	R	2.00	59724	27889	216.00	855.00
GW-609	1	R	4.50	60040	28109	125.00	984.70
GW-609	0	R	0.00	60040	28109	97.00	1012.70
GW-610	1	R	8.00	59472	28549	55.00	1001.78
GW-611	1	H	5.00	58059	28856	55.00	990.43
GW-611	0	H	0.00	58059	28856	85.00	960.43
GW-612	1	R	3.00	58504	28371	81.00	1047.65
GW-612	1	R	15.50	58504	28371	104.00	1024.65
GW-672	0	H	0.00	57042	26269	11.50	915.23
GW-673	1	H	1.00	56904	25567	120.00	760.20
GW-673	0	H	0.00	56904	25567	123.00	757.20
GW-674	0	H	0.00	56911	25578	5.00	875.23
GW-676	0	H	0.00	56563	24226	7.00	836.02
GW-677	0	H	0.00	56260	27484	30.00	997.80
GW-677	0	H	0.00	56260	27484	152.00	875.80
GW-678	1	H	.	56462	27415	130.00	868.10
GW-679	0	H	0.00	56766	27267	115.00	909.20
GW-680	0	H	0.00	57935	27224	115.00	884.80
GW-680	1	H	6.00	57935	27224	44.00	955.80
GW-681	0	H	0.00	58052	26870	100.00	968.50
GW-681	0	H	0.00	58052	26870	119.00	949.50
GW-681	0	H	0.00	58052	26870	185.00	883.50
GW-681	1	H	.	58052	26870	175.00	893.50
GW-681	1	H	12.00	58052	26870	71.00	997.50
GW-682	0	H	0.00	58209	27023	166.00	875.75
GW-682	1	H	20.00	58209	27023	80.00	961.75
GW-683	1	H	1.00	41552	28282	31.00	938.45
GW-683	1	H	5.00	41552	28282	113.00	856.45
GW-683	1	H	9.00	41552	28282	149.00	820.45
GW-683	0	H	0.00	41552	28282	123.00	846.45
GW-684	1	H	1.00	41354	28525	31.00	864.53
GW-709	0	H	0.00	52372	25344	65.60	838.24
GW-709	0	H	0.00	52372	25344	74.50	829.34
GW-710	0	H	0.00	36471	27645	58.00	850.03
GW-710	0	H	0.00	36471	27645	103.00	805.03
GW-710	0	H	0.00	36471	27645	168.00	740.03
GW-710	0	H	0.00	36471	27645	185.30	722.73
GW-710	0	H	0.00	36471	27645	350.00	558.03
GW-710	0	H	0.00	36471	27645	479.70	428.33
GW-711	1	H	3.00	36535	27873	17.50	884.46
GW-711	0	H	0.00	36535	27873	246.00	655.96

Well Number	Type	Loc	Size (ft)	Easting (ft)	Northing (ft)	Depth Water (ft)	Elevation Water (ft)
GW-711	0	H	0.00	36535	27873	65.00	836.96
GW-711	0	H	0.00	36535	27873	120.50	781.46
GW-711	0	H	0.00	36535	27873	186.00	715.96
GW-711	0	H	0.00	36535	27873	284.00	617.96
GW-711	0	H	0.00	36535	27873	299.00	602.96
GW-711	0	H	0.00	36535	27873	316.00	585.96
GW-711	0	H	0.00	36535	27873	412.00	489.96
GW-712	0	V	0.00	36507	28233	114.00	759.61
GW-712	1	V	1.00	36507	28233	13.00	860.61
GW-712	1	V	1.00	36507	28233	15.50	858.11
GW-712	1	V	2.00	36507	28233	20.00	853.61
GW-712	1	V	2.00	36507	28233	22.50	851.11
GW-712	1	V	0.50	36507	28233	28.00	845.61
GW-712	1	V	1.00	36507	28233	47.00	826.61
GW-712	1	V	1.00	36507	28233	62.00	811.61
GW-712	0	V	0.00	36507	28233	38.00	835.61
GW-712	0	V	0.00	36507	28233	85.00	788.61
GW-713	1	V	2.70	36434	28236	31.80	846.03
GW-713	1	V	5.00	36434	28236	35.80	842.03
GW-713	1	V	4.70	36434	28236	43.80	834.03
GW-713	1	V	7.00	36434	28236	54.80	823.03
GW-713	1	V	2.00	36434	28236	66.80	811.03
GW-723	0	H	0.00	49089	29006	60.00	959.31
GW-723	0	H	0.00	49089	29006	94.50	924.81
GW-723	0	H	0.00	49089	29006	119.70	899.61
GW-723	0	H	0.00	49089	29006	127.00	892.31
GW-731	1	R	20.20	63863	27464	109.20	936.55
GW-731	1	R	5.00	63863	27464	140.00	905.75
GW-731	1	R	2.60	63863	27464	164.50	881.25
GW-732	1	R	3.00	64268	27717	93.00	967.65
GW-732	0	R	0.00	64268	27717	181.60	879.05
GW-733	1	H	2.00	65057	28447	45.10	910.59
GW-739	0	H	0.00	49126	29010	118.20	902.46
GW-739	0	H	0.00	49126	29010	97.20	923.46
GW-740	0	H	0.00	49055	29027	71.00	945.95
GW-740	0	H	0.00	49055	29027	98.60	918.35
GW-742	1	R	3.00	58908	28038	93.00	1004.83
GW-742	1	R	1.00	58908	28038	180.00	917.83
GW-742	0	R	0.00	58908	28038	189.50	908.33
GW-742	0	R	0.00	58908	28038	265.00	832.83
GW-742	0	R	0.00	58908	28038	289.50	808.33
GW-742	0	R	0.00	58908	28038	307.00	790.83
GW-742	0	R	0.00	58908	28038	160.00	937.83
GW-743	1	R	1.00	58908	28056	63.50	1035.22
GW-743	1	R	2.50	58908	28056	75.50	1023.22
GW-743	1	R	0.50	58908	28056	88.00	1010.72
GW-743	0	R	0.00	58908	28056	151.50	947.22
GW-520	1	H	19.00	46725	28885	44.00	941.18
GW-601	1	H	.	47629	28903	23.50	975.59
GW-602	1	H	2.00	47430	28640	65.00	1010.06
MIN			0.00	36434	24226	5.00	428.33
MAX			22.40	65057	29027	479.70	1098.06
AVE			1.56	55372	27752	117.41	925.88
STDEV			3.89	8195.12	990.01	74.71	107.66
N	0	0	35.00	0.00	0.00	0.00	0.00
T-N	290	290	255	290	290	290	290

Well Number	Type	Loc	Size (ft)	Easting (ft)	Northing (ft)	Depth Water (ft)	Elevation Water (ft)
Maynardville Limestone							
005-L	1	V	4.50	57000	29500	14.20	928.70
005-L	1	V	.	57000	29500	29.00	913.90
008-L	1	V	6.00	56500	29500	13.70	933.60
008-L	1	V	7.00	56500	29500	24.70	922.60
008-L	1	V	10.30	56500	29500	32.00	915.30
011-L	1	V	0.40	56000	29500	37.80	912.80
017-L	1	V	0.30	55000	29500	12.20	953.90
017-L	1	V	0.50	55000	29500	23.80	942.30
032-L	1	V	0.60	55250	29750	10.00	952.50
032-L	1	V	0.50	55250	29750	17.20	945.30
55-8A(**)	1	V	3.00	55934	29755	19.00	941.00
55-8B (**)	1	V	2.20	55902	29739	19.30	940.70
55-8B (**)	1	V	10.50	55902	29739	27.50	932.50
56-5B	1	V	.	56828	29382	35.10	930.77
56-5C	1	V	3.00	56819	29375	34.00	932.34
56-5C	1	V	1.50	56819	29375	42.00	924.34
60-1C	1	V	2.50	60210	29227	31.00	898.40
60-1C	1	V	0.70	60210	29227	42.50	886.90
60-1C	1	V	2.00	60210	29227	44.50	884.90
60-1C	0	V	0.00	60210	29227	21.20	908.20
60-1C	0	V	0.00	60210	29227	30.00	899.40
60-1C	0	V	0.00	60210	29227	39.50	889.90
BC-49	1	H	0.90	19743	28056	53.40	805.20
BC-50	1	V	0.50	19793	28270	41.40	787.60
BC-57	1	V	0.10	18711	28416	47.30	770.20
BC-57	1	V	1.80	18711	28416	49.80	767.70
GW-114	1	V	15.00	28100	28575	23.50	800.86
GW-117	0	V	0.00	42918	29183	30.00	881.19
GW-118	0	V	0.00	43404	29147	45.00	864.37
GW-119	0	V	0.00	44098	29254	30.00	888.12
GW-122	0	V	0.00	51807	29741	45.00	959.15
GW-123	0	V	0.00	51794	29742	47.00	957.43
GW-124	0	V	0.00	52223	29656	34.00	969.51
GW-125	1	V	2.00	52208	29646	40.50	963.48
GW-125	0	V	0.00	52208	29646	50.00	953.98
GW-149	0	V	0.00	63824	29201	4.00	900.76
GW-149	0	V	0.00	63824	29201	25.00	879.76
GW-151	0	V	0.00	64232	28958	26.00	887.06
GW-153	0	V	0.00	63728	28613	29.00	889.53
GW-154	0	V	0.00	63346	28987	5.00	903.60
GW-172	1	H	3.00	69579	28359	16.00	907.07
GW-172	0	H	0.00	69579	28359	117.00	806.07
GW-172	0	H	0.00	69579	28359	130.00	793.07
GW-213	1	V	3.00	9091	27644	30.00	721.03
GW-213	1	V	4.03	9091	27644	104.00	647.03
GW-213	1	V	4.00	9091	27644	111.00	640.03
GW-214	1	V	.	9091	27701	232.00	518.78
GW-214	0	V	0.00	9091	27701	112.00	638.78
GW-214	0	V	0.00	9091	27701	138.00	612.78
GW-214	0	V	0.00	9091	27701	156.00	594.78
GW-214	0	V	0.00	9091	27701	286.00	464.78
GW-218	1	V	.	58878	29136	9.00	923.77
GW-218	1	V	.	58878	29136	22.50	910.27
GW-218	0	V	0.00	58878	29136	10.50	922.27
GW-220	0	V	0.00	64225	28949	11.00	901.74
GW-222	1	V	.	63324	28954	19.00	889.82
GW-223	1	V	2.00	63311	28938	57.00	851.97
GW-223	0	V	0.00	63311	28938	17.00	891.97
GW-223	0	V	0.00	63311	28938	27.50	881.47
GW-223	0	V	0.00	63311	28938	34.00	874.97
GW-223	0	V	0.00	63311	28938	66.00	842.97

Well Number	Type	Loc	Size (ft)	Easting (ft)	Northing (ft)	Depth Water (ft)	Elevation Water (ft)
GW-223	0	V	0.00	63311	28938	68.50	840.47
GW-225	0	V	0.00	47461	29155	30.00	910.21
GW-226	0	V	0.00	47473	29156	24.00	916.56
GW-226	0	V	0.00	47473	29156	30.00	910.56
GW-227	1	V	0.50	47802	29172	25.50	918.41
GW-227	1	V	0.50	47802	29172	34.50	909.41
GW-227	1	V	0.50	47802	29172	37.00	906.91
GW-228	1	V	0.50	47791	29171	36.00	907.85
GW-228	1	V	1.00	47791	29171	40.00	903.85
GW-228	1	V	10.00	47791	29171	90.00	853.85
GW-229	1	V	12.00	47017	29256	43.00	902.71
GW-229	0	V	0.00	47017	29256	25.00	920.71
GW-229	0	V	0.00	47017	29256	30.00	915.71
GW-230	1	H	8.00	69617	28389	30.00	889.81
GW-230	0	H	0.00	69617	28389	146.00	773.81
GW-230	0	H	0.00	69617	28389	403.00	516.81
GW-232	0	H	0.00	66863	28546	200.00	729.52
GW-235	1	H	7.00	69712	28416	7.00	912.99
GW-235	1	H	3.00	69712	28416	24.00	895.99
GW-235	1	H	8.00	69712	28416	34.00	885.99
GW-235	1	H	2.00	69712	28416	50.00	869.99
GW-238	1	V	3.00	9088	27737	30.00	720.97
GW-238	1	V	2.00	9088	27737	35.00	715.97
GW-240	0	H	0.00	63726	28604	29.00	890.50
GW-251	0	V	0.00	53843	29467	71.00	930.60
GW-278	0	V	0.00	53593	29649	16.00	978.66
GW-279	0	V	0.00	53591	29639	27.00	968.30
GW-279	0	V	0.00	53591	29639	71.00	924.30
GW-280	1	V	1.00	53589	29630	35.00	960.42
GW-280	1	V	1.00	53589	29630	38.00	957.42
GW-280	1	V	1.00	53589	29630	136.00	859.42
GW-280	0	V	0.00	53589	29630	22.00	973.42
GW-280	0	V	0.00	53589	29630	27.00	968.42
GW-306	0	V	0.00	49655	29346	48.00	941.44
GW-309	0	V	0.00	50176	29530	27.00	958.77
GW-309	0	V	0.00	50176	29530	30.00	955.77
GW-309	0	V	0.00	50176	29530	32.50	953.27
GW-309	0	V	0.00	50176	29530	35.70	950.07
GW-313	1	H	3.00	52016	29351	103.00	947.37
GW-313	0	H	0.00	52016	29351	34.00	1016.37
GW-313	0	H	0.00	52016	29351	69.00	981.37
GW-313	0	H	0.00	52016	29351	84.00	966.37
GW-313	0	H	0.00	52016	29351	91.00	959.37
GW-313	0	H	0.00	52016	29351	101.00	949.37
GW-314	1	H	.	52125	29419	30.00	1017.20
GW-314	1	H	.	52125	29419	48.00	999.20
GW-314	0	H	0.00	52125	29419	108.00	939.20
GW-315	1	H	.	52268	29455	62.00	982.84
GW-315	1	H	.	52268	29455	68.50	976.34
GW-315	0	H	0.00	52268	29455	61.50	983.34
GW-315	0	H	0.00	52268	29455	86.50	958.34
GW-315	0	H	0.00	52268	29455	94.50	950.34
GW-348	0	H	0.00	50763	29294	76.40	921.60
GW-349	0	V	0.00	53588	29766	13.00	977.98
GW-350	1	V	2.00	53595	29764	22.00	969.00
GW-350	1	V	.	53595	29764	35.00	956.00
GW-350	0	V	0.00	53595	29764	27.00	964.00
GW-350	0	V	0.00	53595	29764	40.00	951.00
GW-365	0	V	0.00	46490	29150	78.00	855.03
GW-365	0	V	0.00	46490	29150	142.00	791.03
GW-375	1	V	.	44136	29278	15.40	904.08
GW-375	1	V	.	44136	29278	17.50	901.98

Well Number	Type	Loc	Size (ft)	Easting (ft)	Northing (ft)	Depth Water (ft)	Elevation Water (ft)
GW-375	1	V	.	44136	29278	19.80	899.68
GW-375	1	V	.	44136	29278	30.50	888.98
GW-375	1	V	.	44136	29278	36.00	883.48
GW-375	0	V	0.00	44136	29278	29.00	890.48
GW-375	0	V	0.00	44136	29278	129.00	790.48
GW-375	0	V	0.00	44136	29278	160.70	758.78
GW-381	1	V	.	62947	28715	16.30	897.10
GW-381	1	V	.	62947	28715	17.00	896.40
GW-381	1	V	.	62947	28715	19.60	893.80
GW-381	1	V	.	62947	28715	24.50	888.90
GW-382	1	V	.	62956	28716	16.00	897.16
GW-382	0	V	0.00	62956	28716	163.00	750.16
GW-443	1	V	.	31881	28714	42.00	785.75
GW-603	1	H	.	64803	28430	39.00	920.41
GW-603	1	H	2.00	64803	28430	45.00	914.41
GW-603	1	H	3.40	64803	28430	55.00	904.41
GW-603	0	H	0.00	64803	28430	67.00	892.41
GW-604	1	H	4.00	64837	28437	35.00	924.53
GW-604	1	H	4.00	64837	28437	43.00	916.53
GW-604	1	H	2.00	64837	28437	52.50	907.03
GW-604	0	H	0.00	64837	28437	86.00	873.53
GW-604	0	H	0.00	64837	28437	104.50	855.03
GW-605	0	V	0.00	62002	28707	33.00	883.97
GW-606	0	V	0.00	61951	28708	8.00	908.98
GW-606	0	V	0.00	61951	28708	24.00	892.98
GW-606	1	V	3.00	61951	28708	58.00	858.98
GW-606	1	V	1.08	61951	28708	67.00	849.98
GW-616	0	V	0.00	51907	29724	69.00	940.81
GW-618	0	V	0.00	54738	29798	32.00	950.64
GW-620	0	V	0.00	52895	29565	50.20	962.64
GW-620	0	V	0.00	52895	29565	68.00	944.84
GW-621	1	V	16.00	45033	29023	27.00	896.07
GW-645	1	H	4.50	46649	28837	19.00	984.50
GW-645	1	H	1.00	46649	28837	27.00	976.50
GW-645	1	H	4.00	46649	28837	41.00	962.50
GW-645	1	H	2.00	46649	28837	58.00	945.50
GW-645	0	H	0.00	46649	28837	73.50	930.00
GW-645	0	H	0.00	46649	28837	76.00	927.50
GW-646	0	R	0.00	47580	28873	68.00	934.01
GW-647A	0	H	0.00	.	.	13.00	1017.14
GW-648	1	H	2.00	49888	29088	51.00	975.48
GW-648	1	H	2.50	49888	29088	57.50	968.98
GW-648	1	H	1.50	49888	29088	62.50	963.98
GW-648	0	H	0.00	49888	29088	70.50	955.98
GW-652	0	V	0.00	42452	29029	22.50	875.48
GW-684	1	H	1.00	41354	28525	72.00	823.53
GW-684	1	H	2.00	41354	28525	122.00	773.53
GW-684	0	H	0.00	41354	28525	110.00	785.53
GW-685	1	V	1.30	41448	28667	13.70	875.58
GW-685	1	V	2.00	41448	28667	37.00	852.28
GW-685	0	V	0.00	41448	28667	64.00	825.28
GW-685	0	V	0.00	41448	28667	110.00	779.28
GW-688	0	V	0.00	55604	29688	54.00	913.46
GW-690	0	V	0.00	55990	29787	53.00	914.71
GW-692	0	V	0.00	56001	29653	52.00	912.55
GW-692	1	V	.	56001	29653	52.00	961.55
GW-694	0	H	0.00	44893	28845	23.00	915.58
GW-694	0	H	0.00	44893	28845	32.00	906.58
GW-694	0	H	0.00	44893	28845	70.00	868.58
GW-694	0	H	0.00	44893	28845	94.00	844.58
GW-694	0	H	0.00	44893	28845	194.50	744.08
GW-694	0	H	0.00	44893	28845	202.00	736.58

Well Number	Type	Loc	Size (ft)	Easting (ft)	Northing (ft)	Depth Water (ft)	Elevation Water (ft)
GW-694	0	H	0.00	44893	28845	23.00	915.58
GW-694	0	H	0.00	44893	28845	32.00	906.58
GW-694	0	H	0.00	44893	28845	70.00	868.58
GW-694	0	H	0.00	44893	28845	94.00	844.58
GW-694	0	H	0.00	44893	28845	194.50	744.08
GW-696	0	V	0.00	56810	29277	202.00	767.78
GW-697	0	V	0.00	56806	29277	10.00	959.81
GW-698	0	V	0.00	56804	29277	75.00	895.09
GW-698	1	V	.	56804	29277	42.00	928.09
GW-699	0	V	0.00	56844	29168	9.00	957.39
GW-700	0	V	0.00	56828	29452	30.50	927.28
GW-703	0	H	0.00	44931	28806	47.50	904.30
GW-703	0	H	0.00	44931	28806	57.50	894.30
GW-703	0	H	0.00	44931	28806	160.00	791.80
GW-704	0	H	0.00	44935	28845	50.00	891.99
GW-704	0	H	0.00	44935	28845	110.00	831.99
GW-704	0	H	0.00	44935	28845	255.00	686.99
GW-705	0	V	0.00	44916	28945	10.00	914.96
GW-705	0	V	0.00	44916	28945	79.00	845.96
GW-705	0	V	0.00	44916	28945	120.00	804.96
GW-705	0	V	0.00	44916	28945	180.00	744.96
GW-706	0	V	0.00	44944	28946	116.00	809.78
GW-706	0	V	0.00	44944	28946	133.00	792.78
GW-706	0	V	0.00	44944	28946	171.50	754.28
GW-706	0	V	0.00	44944	28946	175.50	750.28
GW-711	0	H	0.00	36535	27873	650.00	251.96
GW-712	0	V	0.00	36507	28233	271.00	602.61
GW-712	0	V	0.00	36507	28233	274.00	599.61
GW-712	0	V	0.00	36507	28233	155.20	718.41
GW-712	0	V	0.00	36507	28233	180.20	693.41
GW-712	0	V	0.00	36507	28233	311.00	562.61
GW-712	0	V	0.00	36507	28233	341.20	532.41
GW-712	0	V	0.00	36507	28233	403.50	470.11
GW-712	0	V	0.00	36507	28233	408.50	465.11
GW-712	0	V	0.00	36507	28233	430.50	443.11
GW-712	0	V	0.00	36507	28233	438.50	435.11
GW-712	0	V	0.00	36507	28233	447.50	426.11
GW-713	1	V	1.50	36434	28236	163.00	714.83
GW-713	1	V	1.00	36434	28236	218.80	659.03
GW-713	0	V	0.00	36434	28236	199.80	678.03
GW-713	0	V	0.00	36434	28236	144.00	733.83
GW-713	0	V	0.00	36434	28236	224.00	653.83
GW-713	0	V	0.00	36434	28236	272.80	605.03
GW-713	0	V	0.00	36434	28236	308.00	569.83
GW-714	1	V	.	36435	28422	42.00	830.30
GW-714	1	V	.	36435	28422	58.00	814.30
GW-714	1	V	.	36435	28422	107.00	765.30
GW-714	0	V	0.00	36435	28422	33.00	839.30
GW-714	0	V	0.00	36435	28422	133.00	739.30
GW-714	0	V	0.00	36435	28422	34.50	837.80
GW-715	0	V	0.00	36453	28425	43.60	828.57
GW-715	1	V	1.00	36453	28425	37.60	834.57
GW-722	1	H	7.00	64926	28532	58.50	892.54
GW-722	1	H	3.10	64926	28532	100.00	851.04
GW-722	0	H	0.00	64926	28532	86.50	864.54
GW-722	0	H	0.00	64926	28532	313.50	637.54
GW-722	0	H	0.00	64926	28532	334.00	617.04
GW-722	0	H	0.00	64926	28532	490.00	461.04
GW-723	0	H	0.00	49089	29006	140.70	878.61
GW-723	0	H	0.00	49089	29006	150.00	869.31
GW-723	0	H	0.00	49089	29006	162.00	857.31
GW-723	0	H	0.00	49089	29006	183.00	836.31

Well Number	Type	Loc	Size (ft)	Easting (ft)	Northing (ft)	Depth Water (ft)	Elevation Water (ft)
GW-723	0	H	0.00	49089	29006	200.60	818.71
GW-723	0	H	0.00	49089	29006	235.00	784.31
GW-723	0	H	0.00	49089	29006	241.00	778.31
GW-723	0	H	0.00	49089	29006	298.60	720.71
GW-723	0	H	0.00	49089	29006	321.60	697.71
GW-723	0	H	0.00	49089	29006	431.50	587.81
GW-724	1	H	2.00	48995	29198	36.50	940.12
GW-724	1	H	1.00	48995	29198	54.00	922.62
GW-724	0	H	0.00	48995	29198	89.60	887.02
GW-724	0	H	0.00	48995	29198	138.60	838.02
GW-724	0	H	0.00	48995	29198	147.60	829.02
GW-724	0	H	0.00	48995	29198	156.00	820.62
GW-724	0	H	0.00	48995	29198	165.00	811.62
GW-724	0	H	0.00	48995	29198	179.00	797.62
GW-724	0	H	0.00	48995	29198	195.00	781.62
GW-724	0	H	0.00	48995	29198	201.60	775.02
GW-724	0	H	0.00	48995	29198	231.60	745.02
GW-724	0	H	0.00	48995	29198	242.00	734.62
GW-724	0	H	0.00	48995	29198	274.60	702.02
GW-724	0	H	0.00	48995	29198	299.00	677.62
GW-725	0	V	0.00	48989	29405	7.00	951.26
GW-725	0	V	0.00	48989	29405	78.50	879.76
GW-725	0	V	0.00	48989	29405	106.00	852.26
GW-725	0	V	0.00	48989	29405	136.10	822.16
GW-725	0	V	0.00	48989	29405	104.50	853.76
GW-725	0	V	0.00	48989	29405	124.50	833.76
GW-725	0	V	0.00	48989	29405	142.50	815.76
GW-733	0	H	0.00	65057	28447	152.00	803.69
GW-733	0	H	0.00	65057	28447	178.20	777.49
GW-733	0	H	0.00	65057	28447	217.20	738.49
GW-733	0	H	0.00	65057	28447	100.10	855.59
GW-733	0	H	0.00	65057	28447	105.10	850.59
GW-733	0	H	0.00	65057	28447	125.10	830.59
GW-733	0	H	0.00	65057	28447	168.10	787.59
GW-733	0	H	0.00	65057	28447	185.10	770.59
GW-733	0	H	0.00	65057	28447	249.50	706.19
GW-734	1	V	3.90	64943	28682	41.50	895.92
GW-734	1	V	1.00	64943	28682	49.00	888.42
GW-734	1	V	1.40	64943	28682	54.00	883.42
GW-734	1	V	44.00	64943	28682	59.40	878.02
GW-736	0	V	0.00	48936	29381	4.00	953.55
GW-736	0	V	0.00	48936	29381	57.50	900.05
GW-736	0	V	0.00	48936	29381	94.00	863.55
GW-737	1	V	2.00	48890	29365	83.00	874.50
GW-737	0	V	0.00	48890	29365	55.60	901.90
GW-737	0	V	0.00	48890	29365	4.00	953.50
GW-738	0	H	.	49026	29150	84.00	896.36
GW-738	0	H	.	49026	29150	89.00	891.36
GW-738	1	H	2.00	49026	29150	41.10	939.26
GW-738	1	H	1.40	49026	29150	50.10	930.26
GW-738	1	H	2.00	49026	29150	75.10	905.26
GW-738	0	H	0.00	49026	29150	33.50	946.86
GW-739	0	H	0.00	42126	29010	136.20	884.46
GW-739	0	H	0.00	42126	29010	172.20	848.46
GW-739	0	H	0.00	42126	29010	186.20	834.46
GW-739	0	H	0.00	42126	29010	224.50	796.16
GW-739	0	H	0.00	42126	29010	243.20	777.46
GW-739	0	H	0.00	42126	29010	247.20	773.46
GW-739	0	H	0.00	42126	29010	127.50	893.16
GW-739	0	H	0.00	42126	29010	147.50	873.16
GW-739	0	H	0.00	42126	29010	263.00	757.66
GW-739	0	H	0.00	42126	29010	274.00	746.66

Well Number	Type	Loc	Size (ft)	Easting (ft)	Northing (ft)	Depth Water (ft)	Elevation Water (ft)
GW-740	0	H	0.00	49055	29027	117.00	899.95
GW-740	0	H	0.00	49055	29027	187.50	829.45
J-001	1	V	1.90	56995	29266	25.80	916.78
J-001	0	V	0.00	56995	29266	29.00	913.58
J-002	1	V	4.30	57007	29365	16.90	928.18
J-002	1	V	1.90	57007	29365	28.30	916.78
J-003	1	V	1.30	57020	29464	4.50	940.17
J-003	1	V	2.30	57020	29464	7.00	937.67
J-003	1	V	0.90	57020	29464	13.30	931.37
J-003	1	V	2.10	57020	29464	15.30	929.37
J-004	1	V	1.00	57033	29563	20.50	927.33
J-005	1	V	1.20	57046	29662	20.00	932.25
J-007	1	V	3.20	57192	29240	26.90	914.18
J-008	1	V	8.00	57219	29438	14.00	931.42
J-008	1	V	0.80	57219	29438	30.00	915.42
J-009	1	V	0.80	57244	29637	20.00	936.96
J-009	1	V	1.00	57244	29637	21.30	935.66
J-009	1	V	2.00	57244	29637	25.70	931.26
J-009	1	V	0.60	57244	29637	35.50	921.46
J-011	1	V	9.10	57391	29214	8.70	929.97
J-011	1	V	2.10	57391	29214	22.30	916.37
J-011	1	V	0.60	57391	29214	28.90	909.77
J-012	1	V	6.20	57417	29413	20.80	921.28
J-015	0	V	0.00	57585	29168	4.00	935.47
J-017	1	V	2.30	57639	29565	8.70	935.47
J-017	1	V	1.00	57639	29565	18.00	926.17
J-019	1	V	0.50	56796	29292	15.50	928.75
J-019	1	V	1.00	56796	29292	20.00	924.25
J-020	1	V	3.70	56822	29490	25.00	922.75
J-020	0	V	0.00	56822	29490	7.00	940.75
K-020	1	H	1.60	62400	28600	10.20	909.52
K-020	1	H	0.20	62400	28600	21.80	897.92
K-020	1	H	0.40	62400	28600	29.80	889.92
K1-015	1	V	19.20	64000	28850	17.70	894.68
K1-015	1	V	18.75	64000	28850	40.25	872.13
K2-015	1	V	18.60	64005	28850	18.70	893.80
GW-727	1	.	.	42540	28734	36.00	861.96
GW-727	1	.	.	42540	28734	40.00	857.96
GW-727	0	.	.	42540	28734	105.00	792.96
GW-727	0	.	.	42540	28734	35.00	862.96
GW-727	0	.	.	42540	28734	162.00	735.96
GW-727	0	.	.	42540	28734	204.50	693.46
GW-729	0	.	.	.	.	370.00	.
GW-729	0	.	.	.	.	386.00	.
GW-730	1	.	.	44608	28921	42.00	880.64
GW-730	1	.	.	44608	28921	73.00	849.64
GW-730	1	.	.	44608	28921	79.00	843.64
GW-730	0	.	.	44608	28921	108.00	814.64
GW-730	0	.	.	44608	28921	156.00	766.64
GW-730	0	.	.	44608	28921	188.00	734.64
GW-730	0	.	.	44608	28921	250.00	672.64
GW-730	0	.	.	44608	28921	264.00	658.64
GW-790	1	.	.	.	.	69.00	.
GW-790	1	.	.	.	.	199.30	.
GW-790	1	.	.	.	.	236.50	.
GW-790	0	.	.	.	.	114.00	.
GW-790	0	.	.	.	.	144.00	.
GW-790	0	.	.	.	.	182.00	.
GW-790	0	.	.	.	.	195.50	.
GW-790	0	.	.	.	.	240.00	.
GW-790	1	.	.	.	.	201.00	.
GW-193	1	V	3.00	59536	29344	9.00	922.11

Well Number	Type	Loc	Size (ft)	Easting (ft)	Northing (ft)	Depth Water (ft)	Elevation Water (ft)
GW-204	0	V	0.00	57411	29956	5.60	949.87
GW-316	1	H	.	52412	29336	39.50	1005.23
GW-316	0	H	0.00	52412	29336	69.00	975.73
GW-316	0	H	0.00	52412	29336	71.00	973.73
GW-316	0	H	0.00	52412	29336	76.00	968.73
GW-317	0	H	0.00	52192	29285	110.00	950.80
GW-317	0	H	0.00	52192	29285	122.00	938.80
GW-317	0	H	0.00	52192	29285	128.00	932.80
GW-366	1	H	.	46708	28886	62.00	923.66
GW-367	0	H	0.00	46695	28884	64.00	922.21
GW-367	0	H	0.00	46695	28884	68.00	918.21
GW-367	0	H	0.00	46695	28884	71.00	915.21
GW-367	0	H	0.00	46695	28884	112.00	874.21
GW-367	0	H	0.00	46695	28884	127.00	859.21
GW-368	0	H	0.00	47618	28913	225.00	773.63
GW-534	1	V	.	49492	30393	21.00	976.43
GW-534	1	V	0.50	49492	30393	22.50	974.93
GW-538	1	V	.	49379	30329	31.00	962.97
GW-538	1	V	.	49379	30329	37.50	956.47
MIN			0.00	0	0	4.00	0.00
MAX			44.00	69712	30393	650.00	1017.20
AVE			1.06	48789	28113	94.24	832.19
STDEV			3.38	14196	5039	96.69	180.84
N	0	25	58.00	12	12	0.00	10.00
T-N	390	365	390	378	378	390	380

N = the number of missing observations

T-N = the total number of observations minus the number of missing observations

Appendix B. Selected GLM model results for transformed and nontransformed data

File Name	R^2	Loc	East	North	DBC	Elev	East*Loc	North*Loc	DBC*Loc	Elev*Loc	East*East	North*North	Elev*Elev	DBC*DBC	E*Elev	N*Elev
Ccr - Nontransformed Data																
Ccr-2	0.72	X	X	X	X	X			X	X						
DF	(n=39)	1	1	1	1	1			1	1						
TYPE III		34.2	0.16	4.1	34.5	34.7			34.2	34.2						
P-value		0.0001	0.682	0.043	0.0001	0.0001			0.0001	0.0001						
Ccr - Transformed Data																
Ln(size + 1) transformation used in all of the following Ccr analyses:																
Ccr-6	0.58	X	X*	X*	X	X*			X	X						
DF	(n=39)	1	1	1	1	1			1	1						
TYPE III		0.68	0.16	0.94	0.68	0.76			0.61	0.68						
P-value		0.0733	0.3728	0.0374	0.0737	0.0591			0.0894	0.0732						
Ccr-9	0.75	X	X*	X*	X	X*	X									
DF	(n=39)	1	1	1	1	1	1									
TYPE III		3.2	3.2	0.9	0.4	0.7	3.2									
P-value		0.0001	0.0001	0.0086	0.0626	0.0178	0.0001									
Cmn - Nontransformed data																
Cmn1-all	0.23	X	X	X		X	X	X		X	X	X	X		X	X
DF	(n=390)	1	1	1		1	1	1		1	1	1	1		1	1
TYPE III		0.004	0.23	0.06		2.6	0.001	0.004		0.32	0.08	0.04	5.51		0.3159	2.395
P-value		0.9194	0.4543	0.6917		0.0119	0.9532	0.9244		0.3766	0.6567	0.7509	0.0003		0.3783	0.0157
This file used depth																
Cmn-all	0.22	X	X	X		X	X	X		X	X	X	X		X	X
DF	(n=390)	1	1	1		1	1	1		1	1	1	1		1	1
TYPE III		0.06	1.05	0.16		2.73	0.009	0.07		0.61	0.35	0.71	6.8		0.0241	5.161
P-value		0.7126	0.1106	0.5325		0.0104	0.8811	0.6913		0.225	0.3571	0.191	0.0001		0.8089	0.0005
This file used elevation																

File Name	R^2	Loc	East	North	DBC	Elev	East*Loc	North*Loc	DBC*Loc	Elev*Loc	East*East	North*North	Elev*Elev	DBC*DBC	E*Elev	N*Elev
Cmn - Transformed Data																
Ln(size + 1) transformation used in the following Cmn analyses:																
all wells, no DBC																
Cmn-1	0.14	X	X*	X*		X*	X					X	X			
DF	(n=390)	1	1	1		1	1					1	1			
TYPE III		0.006	3.1	1.7		1.3	0.08					1.6	1.6			
P-value		0.9006	0.0068	0.0463		0.0806	0.668					0.0533	0.0542			
Cmn-2	0.11		X*	X*		X*						X	X			
DF	(n=390)		1	1		1						1	1			
TYPE III			2.8	3.8		1						1.25	3.6			
P-value			0.0115	0.0033		0.1278						0.0889	0.0041			
Partially Transformed Data																
The ln(size + 1) transformation is made if the symbol @ appears in the following:																
Ccr-par1	0.81	X	X*	X*	X	X	X					X	X			
DF	(n=39)	1	1	1	1	1	1					1	1			
TYPE III	@	3.4	3.4	0.006	0.02	0.12	3.4					0.006	0.55			
P-value		0.001	0.001	0.8055	0.6217	0.2548	0.0001					0.7912	0.0193			
Ccr-par2	0.76	X	X*	X*	X	X	X					X	X			
DF	(n=39)	1	1	1	1	1	1					1	1			
TYPE III		36.7	36.7	0.1	0.009	0.71	36.7					0.1	2.26			
P-value		0.0001	0.0001	0.7313	0.9175	0.3536	0.0001					0.7227	0.104			
Ccr-par3	0.8	X	X	X	X	X*	X					X	X			
DF	(n=39)	1	1	1	1	1	1					1	1			
TYPE III	@	3.4	3.4	0.05	0.00002	0.37	3.4					0.05	0.32			
P-value		0.0001	0.0001	0.4809	0.9884	0.0585	0.0001					0.4707	0.0767			
Ccr-par4	0.76	X	X	X	X	X*	X					X	X			
DF	(n=39)	1	1	1	1	1	1					1	1			
TYPE III		36.7	36.7	0.4	0.06	1.1	36.7					0.4	0.9			
P-value		0.0001	0.0001	0.4881	0.7831	0.2616	0.0001					0.4817	0.3086			
Ccr-par5	0.81	X	X	X	X	X	X					X	X			
DF	(n=39	1	1	1	1	1	1					1	1			
TYPE III	@	3.4	3.4	0.006	0.02	0.11	3.4					0.006	0.55			
P-value		0.0001	0.0001	0.8049	0.662	0.2712	0.0001					0.7916	0.0194			

File Name	R^2	Loc	East	North	DBC	Elev	East*Loc	North*Loc	DBC*Loc	Elev*Loc	East*East	North*North	Elev*Elev	DBC*DBC	E*Elev	N*Elev
Cmn-par1	0.4	X	X*	X*	X	X	X	X	X	X	X	X	X	X		
DF	(n=133)	1	1	1	1	1	1	1	1	1	1	1	1	1		
TYPE III	@	0.03	0.0004	0.42	0.08	0.11	2.4	0.03	0.33	0.31	0.01	0.04	0.4	0.04		
P-value		0.7015	0.9596	0.6127	0.4799	0.4071	0.0002	0.6841	0.1578	0.1674	0.8064	0.6274	0.1177	0.606		
Cmn-par2	0.3	X	X*	X*	X	X	X	X	X	X	X	X	X	X		
DF	(n=133)	1	1	1	1	1	1	1	1	1	1	1	1	1		
TYPE III		15.2	0.005	0.2	2.5	0.0008	81.65	17.2	0.08	0.01	0.23	0.15	1.1	0.22		
P-value		0.2673	0.9839	0.8981	0.6495	0.9936	0.011	0.2383	0.9362	0.975	0.8915	0.9125	0.7665	0.8942		
Cmn-par3	0.4	X	X	X	X	X*	X	X	X	X	X	X	X	X		
DF	(n=133)	1	1	1	1	1	1	1	1	1	1	1	1	1		
TYPE III	@	0.5	0.0007	0.03	0.07	0.9	2.1	0.08	0.23	0.27	0.003	0.03	1	0.01		
P-value		0.08096	0.9474	0.6456	0.5115	0.0197	0.0005	0.4853	0.2381	0.1955	0.8992	0.6632	0.0147	0.7938		
Cmn-par4	0.3	X	X	X	X	X*	X	X	X	X	X	X	X	X		
DF	(n=133)	1	1	1	1	1	1	1	1	1	1	1	1	1		
TYPE III		41.9	0.04	0.005	4.2	5.5	67.6	24.8	1.1	0.6	0.1	0.02	6.6	0.15		
P-value		0.0665	0.9531	0.9838	0.557	0.5018	0.0203	0.1572	0.7697	0.8253	0.9263	0.9671	0.4631	0.9132		

Note : An "X" followed by an * indicates that the transformed version of the data was used in the analysis.
The transformations are as follows: ln(size + 1) for size; east in km rather than ft; north in km rather than ft; ln(elev) for elev.
"n" is the sample size.
DF = Degrees of freedom. Type III = Type 3 sums of squares.
The P-value is the probability of obtaining the observed F-statistic or larger under the hypothesis that the variable has no effect.

Appendix C. Comparison of selected GLM model results with and without the use of the DBC variable. The ln(Size+1) transformation is used in all of the following.

File Name	R^2	Loc	East	North	DBC	Elev	East*Loc	North*Loc	DBC*Loc	Elev*Loc	East*East	North*North	Elev*Elev	DBC*DBC	East*Elev	North*Elev
Ccr																
Ccr-14	0.81	X	X*	X*	X	X*	X					X	X			
DF	n=39	1	1	1	1	1	1					1	1			
TYPE III		3.4	3.4	0.06	0.002	0.29	3.4					0.06	0.24			
P-value		0.0001	0.0001	0.45	0.893	0.089	0.0001					0.441	0.118			
Ccr-15	0.81	X	X*	X*		X*	X					X	X			
DF	n=39	1	1	1		1	1					1	1			
TYPE III		3.4	3.4	1		0.57	3.4					1.04	0.58			
P-value		0.0001	0.0001	0.002		0.018	0.0001					0.002	0.017			
Ccr-16	0.108	X	X*	X*		X*	X					X	X			
DF	n=289	2	1	1		1	2					1	1			
TYPE III		3.9	3.75	6.19		0.008	3.78					6.11	0.02			
P-value		0.201	0.814	0.002		0.901	0.447					0.002	0.852			
Cmn																
cmn-all	0.23	X	X*	X*		X	X*	X*		X	X*	X*	X		X*	X*
DF	n=390	1	1	1		1	1	1		1	1	1	1		1	1
TYPE III		0.046	0.744	0.859		5.983	0.033	0.05		0.01	0.232	1.097	5.896		0.225	6.149
P-value		0.737	0.178	0.859		0.0002	0.778	0.727		0.873	0.451	0.102	0.0002		0.459	0.0001
Cmn-13	0.4	X	X*	X*	X	X*	X	X	X	X	X	X	X	X		
DF	n=133	1	1	1	1	1	1	1	1	1	1	1	1	1		
TYPE III		0.06	0.004	0.0002	0.0015	0.54	0.64	0.006	0.19	0.22	0.007	0.0002	0.46	0.01		
P-value		0.537	0.869	0.973	0.924	0.07	0.049	0.851	0.287	0.248	0.841	0.975	0.093	0.807		
Cmn-5	0.31	X	X*	X*	X	X*	X									
DF	n-133	1	1	1	1	1	1									
TYPE III		3.8	1.6	2.3	0.12	0.87	4.5									
P-value		0.0001	0.003	0.0004	0.402	0.028	0.0001									
Cmn-5a	0.308	X	X*	X*		X*	X									
DF	n=133	1	1	1		1	1									
TYPE III		3.69	3.92	3.87		1.38	4.47									
P-value		0.0001	0.0001	0.0001		0.006	0.0001									

Note : n=39 labels in the second column indicate the sample size for the particular model.

An "X" followed by an * indicates that the transformed version of the data was used in the analysis.

The transformations are as follows: ln(Size + 1) for Size; East in km rather than ft; North in km rather than ft; ln(Elev) for Elev.

Appendix D. Summary of selected logistic regression model results. Variables are transformed unless otherwise noted.

	Sample Size	% Correct	Intercept	D1	D2	East	North	Elev	E x E	E x N	E x D1	E x D2	E x Elev	N x N	N x D1	N x D2	N x Elev	D1 x Elev	D2 x Elev	Elv x Elv
Ccr																				
ccr1a-all	290	64.50%																		
P-value			0.370	0.075	0.272	0.749	0.700	0.454	0.691	0.750	0.870		0.875	0.030	0.957		0.463	0.085	0.262	0.356
Param			760.2	-86.3	260.7	-2.8	-31.7	-164.6	-0.02	0.19	0.04		0.23	6.3	-0.13		11.3	12.5	-39.7	17.9
Std. Err.			842.8	48.4	237.2	8.9	82.1	219.7	0.05	0.60	0.26		1.5	2.9	2.5		15.4	7.3	35.3	19.4
ccr3a-all	278	65.80%																		
P-value			0.990	0.471	0.183	0.775	0.706	0.871	0.643	0.207	0.997		0.348	0.005	0.684		0.064	0.628	0.177	0.227
Param			-8.1	-37.8	308.1	2.8	34.3	-36.6	-0.02	0.90	0.00		-1.5	10.3	1.2		-32.8	3.8	-46.5	24.3
Std. Err.			889.0	52.5	231.6	9.8	91.1	225.1	0.05	0.70	0.30		1.6	3.6	2.9		17.7	7.8	34.5	20.1
ccr4-all	278	65.80%																		
P-value			0.990	0.470	0.180	0.770	0.710	0.870	0.640	0.210	0.990		0.350	0.005	0.680		0.060	0.630	0.180	0.230
Param			-8.1	-37.8	308.1	2.8	34.3	-36.6	-0.02	0.94	0.00		-1.5	10.3	1.2		-32.8	3.8	-46.5	24.3
Std. Err.			889.0	52.5	231.6	9.7	91.1	225.1	0.05	0.75	0.32		1.6	3.6	2.9		17.7	7.8	34.5	20.1
ccr5-all	278	60.80%																		
P-value			0.0001					0.0001											0.0001	
Param			44.2					-6.4											-0.37	
Std. Err.			9.8					1.4											0.10	
(=ccr4 with selection option, slentry=0.15)																				
ccr5-all	278	60.80%																		
P-value			0.0001					0.0001											0.0001	
Param			44.2					-6.4											-0.38	
Std. Err.			9.8					1.4											0.10	
(=ccr4 with selection option, slentry=0.35)																				
ccr5-all	278	60.80%																		
P-value			0.0001					0.0001											0.0003	
Param			44.2					-6.4											-0.38	
Std. Err.			9.8					1.4											0.10	
(=ccr4 with selection option, slentry=0.55)																				

Cmn	Sample Size	% Correct	Intercept	D1	D2	East	North	Elev	E x E	E x N	E x D1	E x D2	E x Elev	N x N	N x D1	N x D2	N x Elev	D1 x Elev	D2 x Elev	Elv x Elv
cmn2-all	378	70.60%																		
P-value			0.030	0.034	0.032	0.050					0.120	0.120	0.300		0.040	0.050	0.050	0.600	0.280	2.400
Param			937.5	-2076.1	-2119.6	19.7					-17.1	-17.2	-0.37		243.3	228.9	-33.2	24.9	50.0	17.6
Std. Err.			442.9	978.2	988.1	10.3					11.0	11.1	0.37		118.3	117.4	17.3	47.2	46.3	11.4
cmn3a-all	378	73.30%																		
P-value			0.320	0.919	0.380	0.109	0.351	0.080	0.753	0.951	0.336	0.297	0.222	0.155	0.061		0.541	0.654	0.308	0.538
Param			1102.1	-10.3	-84.8	12.8	154.9	-539.3	-0.01	0.04	-1.7	-1.9	-1.7	-18.6	10.3		26.1	-8.0	16.4	22.9
Std. Err.			1108.8	101.3	96.6	8.0	166.1	307.6	0.02	0.76	1.8	1.8	1.4	13.1	5.5		42.7	17.9	16.1	37.2
cmn5-all	378	73.30%																		
P-value			0.32	0.92	0.38	0.11	0.35	0.08	0.75	0.95	0.34	0.3	0.22	0.16	0.06		0.54	0.65	0.31	0.54
Param			1102.1	-10.3	-84.8	12.8	154.9	-539.3	-0.01	0.05	-1.7	-1.9	-1.7	-18.6	10.3		26.1	-8.0	16.4	22.9
Std. Err.			1108.8	101.3	96.6	8.0	166.1	307.6	0.02	0.76	1.8	1.8	1.4	13.1	5.5		42.6	17.9	16.1	37.2
cmn6a-all	369	74.00%																		
P-value			0.200	0.735	0.543	0.088	0.569	0.070	0.502	0.963	0.314	0.294	0.235	0.150	0.052		0.429	0.358	0.433	0.582
Param			1601.8	34.5	-57.9	15.2	102.7	-626.1	-0.02	-0.04	-1.7	-1.8	-1.9	-19.8	12.1		36.9	-16.9	12.2	22.7
Std. Err.			1240.0	101.7	95.1	8.9	180.3	354.8	0.02	0.82	1.7	1.7	1.6	13.7	6.2		46.7	18.4	15.6	41.3
deleted influential observations																				
cmn7-all	378	72.00%																		
P-value			0.060			0.004	0.560	0.007	0.900	0.460			0.060	0.006			0.040			0.520
Param			1992.0			20.1	83.6	-733.8	0.00	-0.46			-2.4	-27.4			60.6			16.4
Std. Err.			1088.8			7.0	143.4	273.6	0.02	0.62			1.3	10.0			30.2			25.4
cmn9	378	73.00%																		
P-value			0.280	0.910	0.510	0.080	0.430	0.060	0.750	0.860	0.300	0.290	0.240	0.002			0.030	0.870	0.390	0.790
Param			1183.1	10.2	-58.9	13.7	128.3	-533.2	-0.01	-0.13	-1.9	-1.9	-1.5	-34.2			71.4	2.6	12.6	-7.4
Std. Err.			1099.6	92.2	88.4	7.9	162.0	281.0	0.02	0.78	1.8	1.8	1.3	10.6			32.8	15.3	14.8	28.4
cmn10	378	69.80%																		
P-value			0.0001	0.0001			0.0001							0.0001						0.0001
Param			-1608.6	1.6			368.7							-20.4						-1.3
Std. Err.			368.0	0.3			83.6							4.7						0.19

(ccr9 with selection option, slentry=0.15)

	Sample Size	% Correct	Intercept	D1	D2	East	North	Elev	E x E	E x N	E x D1	E x D2	E x Elev	N x N	N x D1	N x D2	N x Elev	D1 x Elev	D2 x Elev	Elv x Elv
cmn11	378	58.50%																		
P-value			0.0001					0.0001						0.0004						
Param			45.8					-9.2						0.21						
Std. Err.			8.8					1.6						0.06						
used lelev,NxElev,NxN, kmeast: did selection, slentry=0.15																				
cmn15	364	70.30%																		
P-value			0.0001		0.0001		0.0001							0.0001			0.0036			0.0018
Param			-1504.5		-1.7		345.7							-27.2			22.2			-15.8
Std. Err.			376.4		0.33		85.6							5.7			7.6			5.1
same as cmn10, except incomplete observations were deleted.																				
cmn2a	185	81.10%																		
P-value			0.23	0.022		0.167	0.198	0.289	0.912	0.21	0.77		0.302	0.162	0.02		0.346	0.416		0.042
Param			-2315.50	141.2		-269.5	4862	-95.5	-3.59	273.9	-1.17		7.47	-2545.9	-140.8		83.5	1.99		6.02
Std. Err.			1934.00	61.8		194.9	3774.3	89.96	32.3	218.7	4.03		7.23	1819.3	60.6		88.6	2.4		2.96
uses only newer wells (>GW-500), and normalized data																				

Note: P-value is the probability of obtaining the observed F-statistic or larger under the hypothesis that the variable has no effect.

Param. is the value of the parameter estimated by the model.

Std. Err. is the Standard error.

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