

## ABSTRACT

Relations between corrosive ground water, water chemistry, and geology in Pennsylvania were evaluated by use of a modified version of the Langelier Saturation Index (LSI) and a geologic contact dataset in a Geographic Information System. Water-chemistry information for water samples collected from 4,839 combined private and public-supply wells from 1900 to 1993 was used to calculate the LSI. Thirty-eight lithologic subgroups within four major rock types—carbonate, siliciclastic, crystalline, and unconsolidated—in Pennsylvania were grouped together if the mean of ranked LSI values were not significantly different. A water is considered corrosive if the LSI value is negative, preventing the precipitation of calcium carbonate, therefore, allowing corrosive reactions with the interior of piping systems. Statistical tests of the LSI values show the least corrosive waters are in the carbonate lithologic subgroup, and the most corrosive waters are in the quartzite lithologic subgroup. Approximately 58 percent of the 4,839 LSI values were considered moderately to extremely corrosive. A map showing the location of 4,839 wells and associated corrosivity range within 11 lithologic subgroups will aid in identifying potential areas of corrosive ground water in Pennsylvania.

## INTRODUCTION

Corrosion of water-distribution systems can be a serious problem facing the water-utility industry and water users. Corrosion is the "deterioration of a substance or its properties because of chemical, physical, or biological reactions with its environment" (Schock, 1990). Numerous studies have correlated occurrence of corrosive water and leaching of lead, copper, and other trace metals from materials commonly used in water-distribution systems (Barringer and others, 1990; Harrison and Laxen, 1980; Hem and Durum, 1973; Schock, 1980; Millette and others, 1980). Implementation of corrosion-control treatments is required on systems (USEPA) action levels concentrations of lead and copper in excess of the U.S. Environmental Protection Agency (USEPA) action levels. The Lead and Copper Rule (U.S. Environmental Protection Agency, 1991) established the drinking water action levels for concentrations of lead (0.015 milligrams per liter (mg/L)) and copper (1.3 mg/L).

Several corrosion indicators have been developed and utilized to indirectly measure the relative corrosiveness of a water. A corrosion index is a mathematical representation of the corrosion potential of a water on the basis of certain physical and chemical characteristics such as pH, temperature, and concentrations of alkalinity, calcium, dissolved oxygen, and dissolved solids (Kish and others, 1989). Corrosion indices are not direct measures of a water's corrosivity toward metallic components of the water-distribution system but are indicators of a water's ability to dissolve and precipitate calcium carbonate (CaCO<sub>3</sub>). The Langelier Saturation Index (LSI) is the most commonly used and referenced index. Total alkalinity, pH, concentrations of total dissolved solids and calcium, and water temperature are required to calculate LSI values (Langelier, 1936). In general, chemical factors such as acidic pH, low alkalinity, low calcium hardness, and high total-dissolved solids are indicative of corrosive waters in water-supply systems (Schock, 1990). The predominate method of corrosion control (Rossum and Merrill, 1983) involves treatment of the water to neutralize acidity until the condition is achieved where CaCO<sub>3</sub> will precipitate.

Ground water is the sole source of supply to more than one-half of the public water-supply companies and private wells in Pennsylvania (U.S. Geological Survey, 1984). The corrosive nature of ground water in parts of the state can limit suitability of the water for some uses. However, limited information exists concerning corrosive ground water in Pennsylvania. Knowledge of the severity and distribution of corrosive ground water will be beneficial to water-resource managers when planning the development of Pennsylvania's ground-water resources.

This report assesses the severity and distribution of the corrosive characteristics of ground water in Pennsylvania. Specifically, this report shows the spatial distribution of rock type and ground-water-supply wells classified by a corrosion index that is based on ground-water-quality data collected from 1900 to 1993.

## DESCRIPTION OF STUDY AREA

The rocks in Pennsylvania can be grouped into four broad "rock types" on the basis of similar lithologic and geologic characteristics. These four rock types include carbonate rocks, crystalline rocks, siliciclastic rocks, and unconsolidated sediments. Carbonate rocks consist primarily of limestone and dolomite. Approximately 6 percent of the state is underlain by carbonate rock. Crystalline rock is composed mostly of schist, granite, quartzite, and gneiss and underlies approximately 6 percent of the state. Siliciclastic rocks include sandstone, siltstone, shale, and conglomerates and make up the majority of the rock in the state's coal-containing areas. Approximately 87 percent of the state is underlain by siliciclastic rock. Unconsolidated sediments include sands, gravels, and clays and account for less than 1 percent of the area of the state.

Pennsylvania contains parts of seven physiographic provinces: Coastal Plain, Piedmont, New England, Blue Ridge, Ridge and Valley, Appalachian Plateaus, and Central Lowlands (Berg and others, 1989). The Coastal Plain is in the extreme southeast area of the state and consists of gently dipping unconsolidated layers of gravel, sand, and clay underlying flat lowlands. The New England, Piedmont, and Blue Ridge Physiographic Provinces are in the south-central and southeast area of the state between the Coastal Plain and the Ridge and Valley Physiographic Provinces. The three provinces consist of complexly folded and faulted metamorphic and metavolcanic crystalline rocks except for the Piedmont Province, of which approximately 25 percent is predominantly carbonate rocks. Topography of the three provinces ranges from broad, gently-rolling hills to isolated highlands in the New England Province and pronounced ridges and deep valleys in the Blue Ridge Province. The Ridge and Valley Province covers most of the central and south-central areas of the state. The Ridge and Valley Physiographic Province predominantly consists of resistant layers of siliciclastic rocks that have been folded and eroded forming long, narrow ridges separated by long valleys generally underlain by carbonate rocks. The Appalachian Plateau Physiographic Province covers approximately 58 percent of the state and consists entirely of siliciclastic rocks. The topography is generally broad, rounded to flat uplands with buried, broad, deep-angular, and shallow valleys. The seventh province, Central Lowlands, is located in the extreme northwest corner of the state bordering Lake Erie and is characterized by low relief and ridges parallel to the lake consisting of unconsolidated sediments. (U.S. Geological Survey, 1984; Berg and others, 1989).

The chemical weathering or corrosion of rock components by acidic waters has the greatest influence on the concentrations of major ions in ground water in the state. Because of Pennsylvania's complex geology, ground-water supplies commonly are obtained from multiple water-bearing zones, producing a geo-chemical character that is the product of several rock formations (U.S. Geological Survey, 1986). The corrosivity index is based primarily on the pH and the concentrations of alkalinity and calcium in the waters within the aquifers. Generally, the median pH and median concentrations of alkalinity and calcium are greatest in carbonate rocks because of the dissolution of calcite (CaCO<sub>3</sub>) and dolomite [CaMg(CO<sub>3</sub>)<sub>2</sub>]. Median pH and median concentrations of alkalinity and calcium are generally smallest in the crystalline rocks because of the absence of carbonate minerals, resulting in dilute "soft" waters containing few dissolved solids. Minimum pH and maximum concentrations of alkalinity are in the coal-bearing siliciclastic rocks, primarily because of pyrite weathering.

## METHODS AND DATA SOURCES

A modified form of the Langelier Saturation Index (LSI) presented by Rossum and Merrill (1983) was used in this study to calculate the corrosivity index for 4,839 ground-water sites with data retrieved from U.S. Geological Survey data bases. Although the standard form of the LSI is the most commonly used and referenced index for identifying the corrosiveness of water, Rossum and Merrill (1983) reported that the LSI, not the LSI, satisfactorily indicates whether the water is oversaturated, saturated, or undersaturated with CaCO<sub>3</sub>.

The LSI is defined as follows:

$$LSI = pH - pH_{eq} \quad (1)$$

where pH is the negative logarithm of the hydrogen ion concentration; and

$$pH_{eq} = -\log_{10} \left( [Ca^{2+}] \cdot [Alk] \cdot \frac{K_w}{[H^+]} + [H^+] \right) \left( \frac{K_2}{K_1} \cdot \frac{[H^+]}{2K_2 + [H^+]} \right) - \log_{10} f_m \quad (2)$$

where  $K_1$  is CaCO<sub>3</sub> solubility product constant, at specific ionic strength and temperature;

$K_2$  is second dissociation constant for carbonic acid HCO<sub>3</sub><sup>-</sup>, at specific ionic strength and temperature;

$K_w$  is dissociation constant for water, at specific ionic strength and temperature;

[Ca<sup>2+</sup>] is calcium concentration, in moles per liter;

[H<sup>+</sup>] is hydrogen ion concentration, in moles per liter;

Alk is alkalinity, in equivalents per liter; and

$f_m$  is activity coefficient for monovalent ions.

In general, positive LSI values indicate noncorrosive waters that are oversaturated with CaCO<sub>3</sub>; negative values indicate corrosive waters that are undersaturated with CaCO<sub>3</sub>; and an LSI equal to zero indicates a water in equilibrium with CaCO<sub>3</sub>. Waters with positive LSI values tend to precipitate CaCO<sub>3</sub>, coating and protect pipe surfaces from corrosion. Waters with negative LSI values tend to dissolve the protective layer of CaCO<sub>3</sub>, allowing corrosive reactions with the pipe interior (Viessman and Hammer, 1989). The locations of the 4,839 wells and the LSI values were imported into the Geographic Information System (GIS) and saved as a point dataset using ARC/INFO (GIS software). A polygon dataset of geologic contacts identified on the Pennsylvania geologic map by Berg and others (1980) at a scale of 1:500,000 was scanned, digitized, and assigned a code for rock type and lithologic subgroup. For this study, each of the 38 lithologic subgroups mapped by Berg and others (1980) were grouped into 1 of 4 major rock types. The intersection of the point (water-quality data) and polygon (geologic contacts) datasets resulted in a point dataset that included the station number, LSI, rock type, and lithologic subgroups. The Statistical Analysis System (SAS) (SAS Institute, Inc., 1990a) was used to perform statistical tests on the dataset. To reduce the variability and overlap present between the ranked LSI values and the rock type, Tukey's studentized range test (SAS Institute Inc., 1990b) (alpha=0.05) was used to determine if ranked LSI values for 38 different lithologic subgroups varied significantly. This process resulted in 11 significant combinations of lithologic subgroups (table 1).

Table 1. Rock type, description of lithologic subgroups, number of wells, and areal coverage in Pennsylvania

Rock type	Lithologic subgroup	Number of wells	Area (square kilometers)
Carbonate	CARB (carbonate)	748	7,476
Crystalline	CRYST (crystalline, excluding diabase and quartzite)	447	5,525
	DIA (diabase)	50	680
	QTZ (quartzite)	166	593
Siliciclastic	MC/SS/A (anthracite-bearing siliciclastic)	66	1,531
	ML (limestone-bearing siliciclastic)	78	1,732
	ML/B (mixed siliciclastic with bituminous coal, including mixed siliciclastics and mixed siliciclastic with limestone and bituminous coal)	1,566	63,165
	SH (shale)	505	6,541
	SH/MISC (predominantly shale siliciclastic)	483	12,899
	SS/MISC (predominantly sandstone siliciclastic)	500	16,814
Unconsolidated	UNC (unconsolidated)	228	491

## RESULTS

Significant differences exist between rock type with respect to mean ranked LSI values. A cumulative frequency plot (fig. 1) of the LSI values of the four rock types illustrates the differences between medians (cumulative frequency equals 50 percent) and the ranges in variability. The median LSI values indicate the least corrosive waters are in the carbonate rock type (-0.02), and the most corrosive waters are in the crystalline rocks, where the median LSI value was -2.81. The LSI values for carbonate rocks are the least variable; 90 percent are within the range -1.2 to 0.60. The LSI values for crystalline rocks are the most variable; 90 percent are within the range -6.1 to 0.19.

Significant differences between ranked LSI values indicate two of the subgroups (carbonate and quartzite) are significantly different from all other subgroups (fig. 2). Eight of the 11 lithologic subgroups are significantly different from all but one other group. Only diabase is not significantly different from more than two other lithologic subgroups.

In order to assess corrosion of public drinking-water supplies in Pennsylvania, the Pennsylvania Department of Environmental Protection (PaDEP) classifies LSI values by use of the following corrosivity scale developed by Medlar (1989):

extreme	(LSI less than -4.0)
high	(LSI greater than or equal to -4.0 and less than -2.0)
moderate	(LSI greater than or equal to -2.0 and less than -0.5)
ideal	(LSI greater than or equal to -0.5 and less than 0.5)
CaCO <sub>3</sub> precipitate	(LSI greater than or equal to 0.5)

Approximately 40 percent of the LSI values grouped by rock type are within the ideal range, and approximately 58 percent of the values are considered to be moderately to extremely corrosive (fig. 3). Only 2 percent of the LSI values were considered capable of precipitating CaCO<sub>3</sub>.

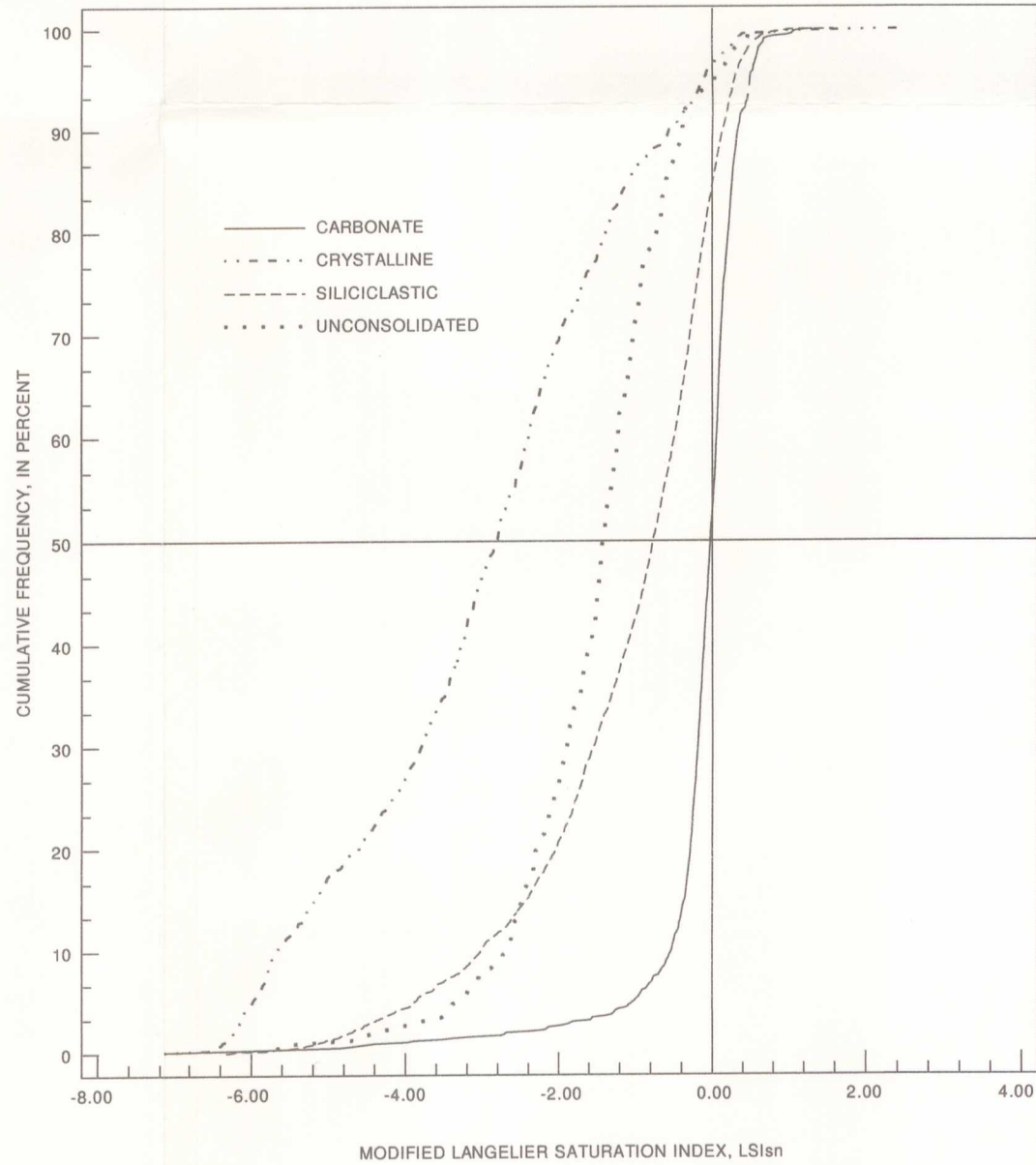


Figure 1. Cumulative frequency of modified Langelier Index values as a function of rock type.

	CARB	CRYST	DIA	QTZ	MC/SS/A	ML	ML/B	SH	SH/MISC	SS/MISC	UNC
CARB											
CRYST											
DIA											
QTZ											
MC/SS/A											
ML											
ML/B											
SH											
SH/MISC											
SS/MISC											
UNC											

EXPLANATION			
CARB	Carbonate	ML/B	Mixed siliciclastic with bituminous coal, including mixed siliciclastics and mixed siliciclastic with limestone and bituminous coal
CRYST	Crystalline, excluding diabase and quartzite		
DIA	Diabase	SH	Shale
QTZ	Quartzite	SH/MISC	Predominantly shale siliciclastic
MC/SS/A	Anthracite-bearing siliciclastic	SS/MISC	Predominantly sandstone siliciclastic
ML	Limestone-bearing siliciclastic	UNC	Unconsolidated
	Significant difference		No significant difference

Figure 2. Significant relations among 11 significant lithologic subgroups using ranked LSI values.

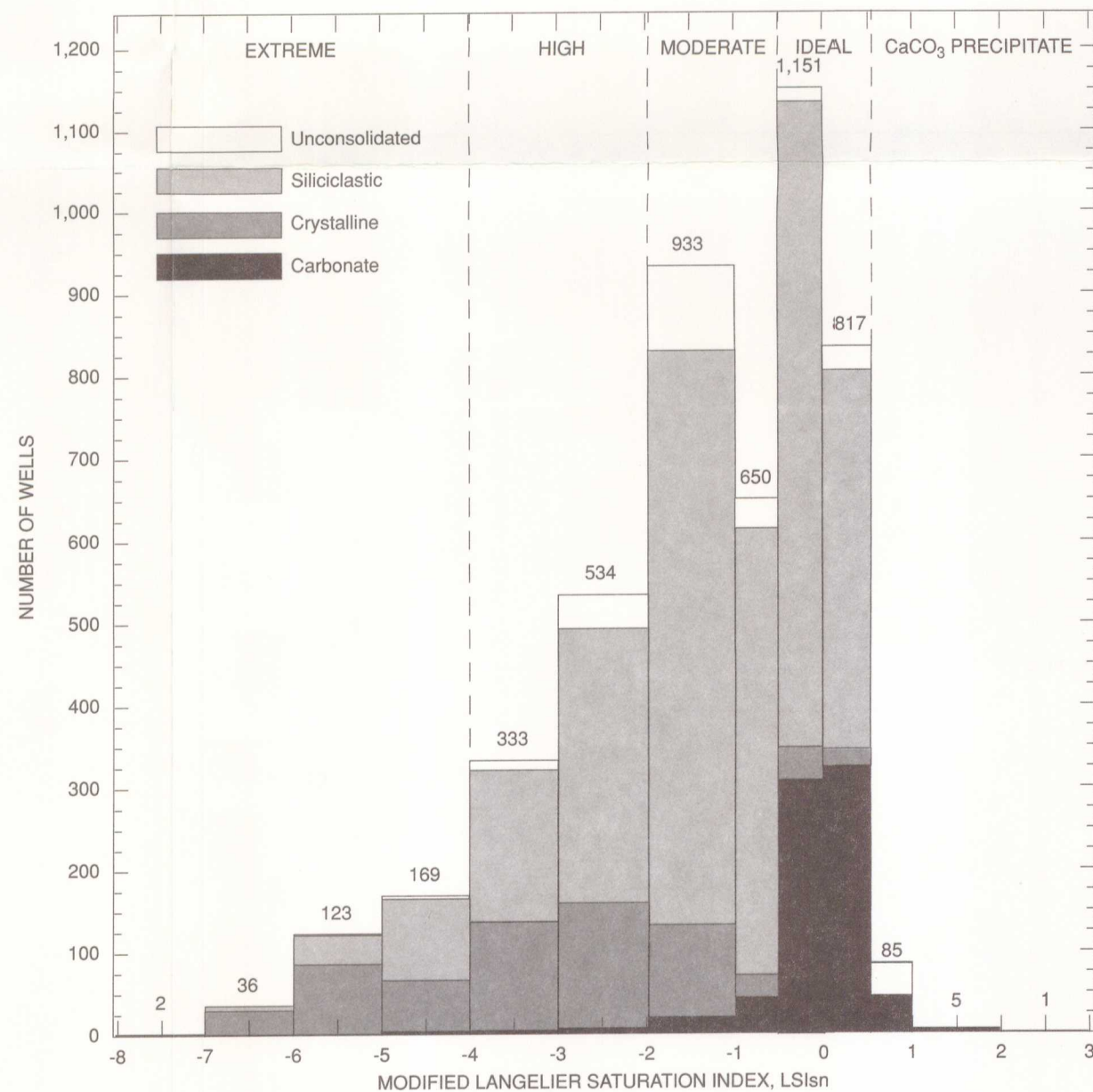
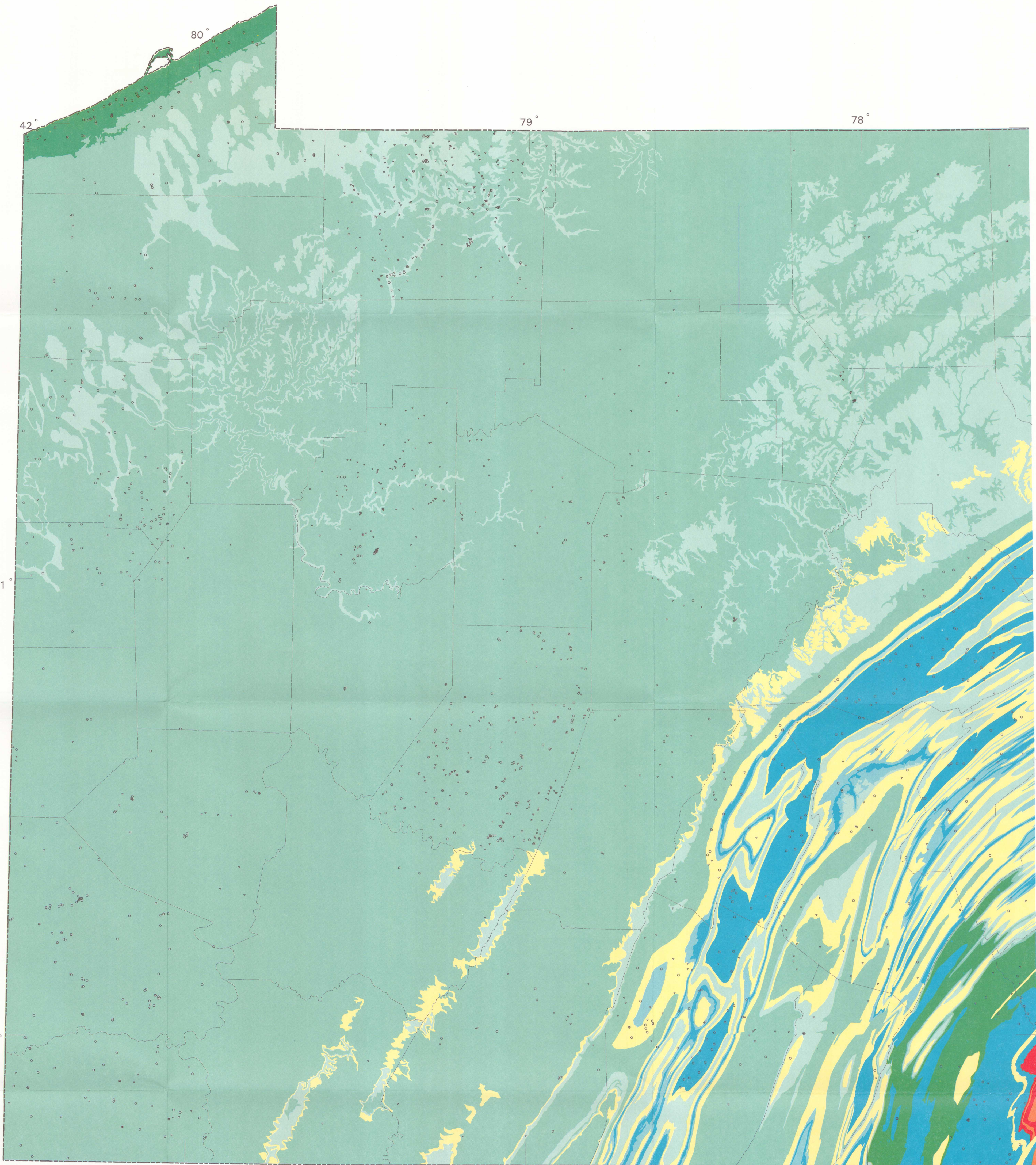
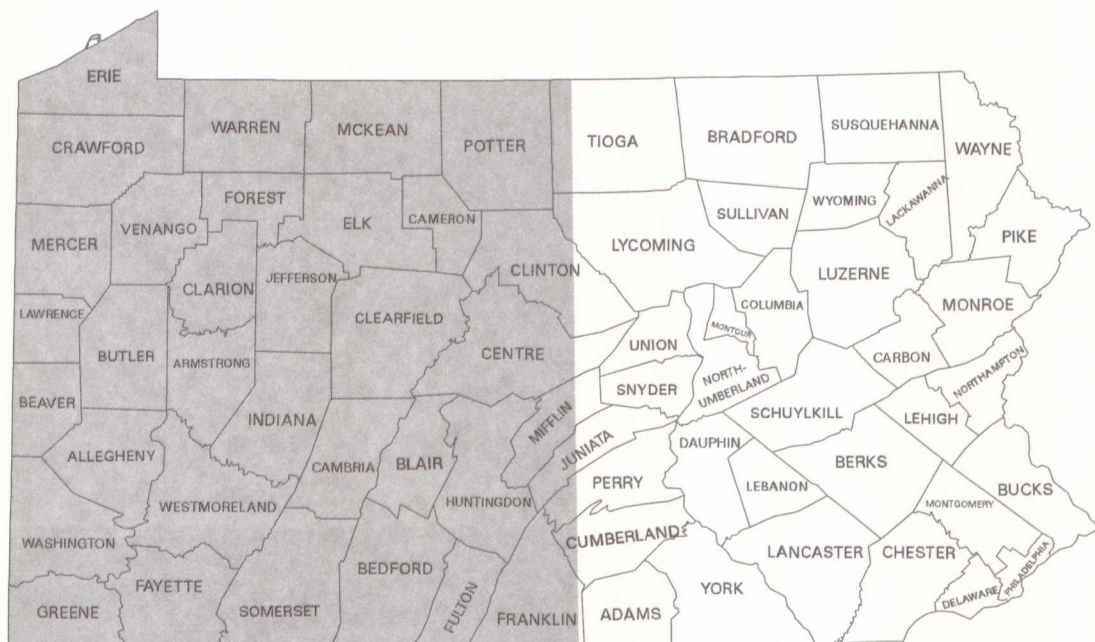
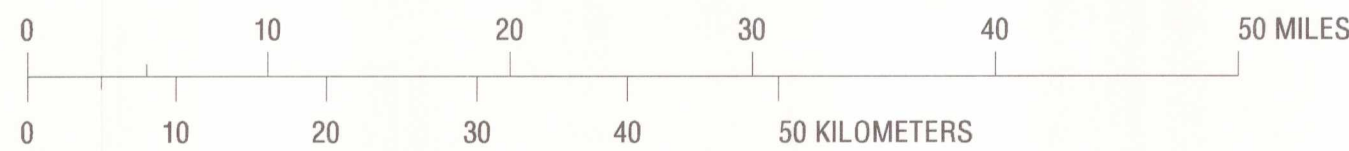


Figure 3. Number of wells in Pennsylvania, grouped by rock type, and Medlar (1989) corrosivity classifications.



Base from U. S. Geological Survey 1:100,000 Digital Line Graphs



## ASSESSMENT OF SEVERITY AND DISTRIBUTION OF CORROSIVE GROUND WATER IN PENNSYLVANIA

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