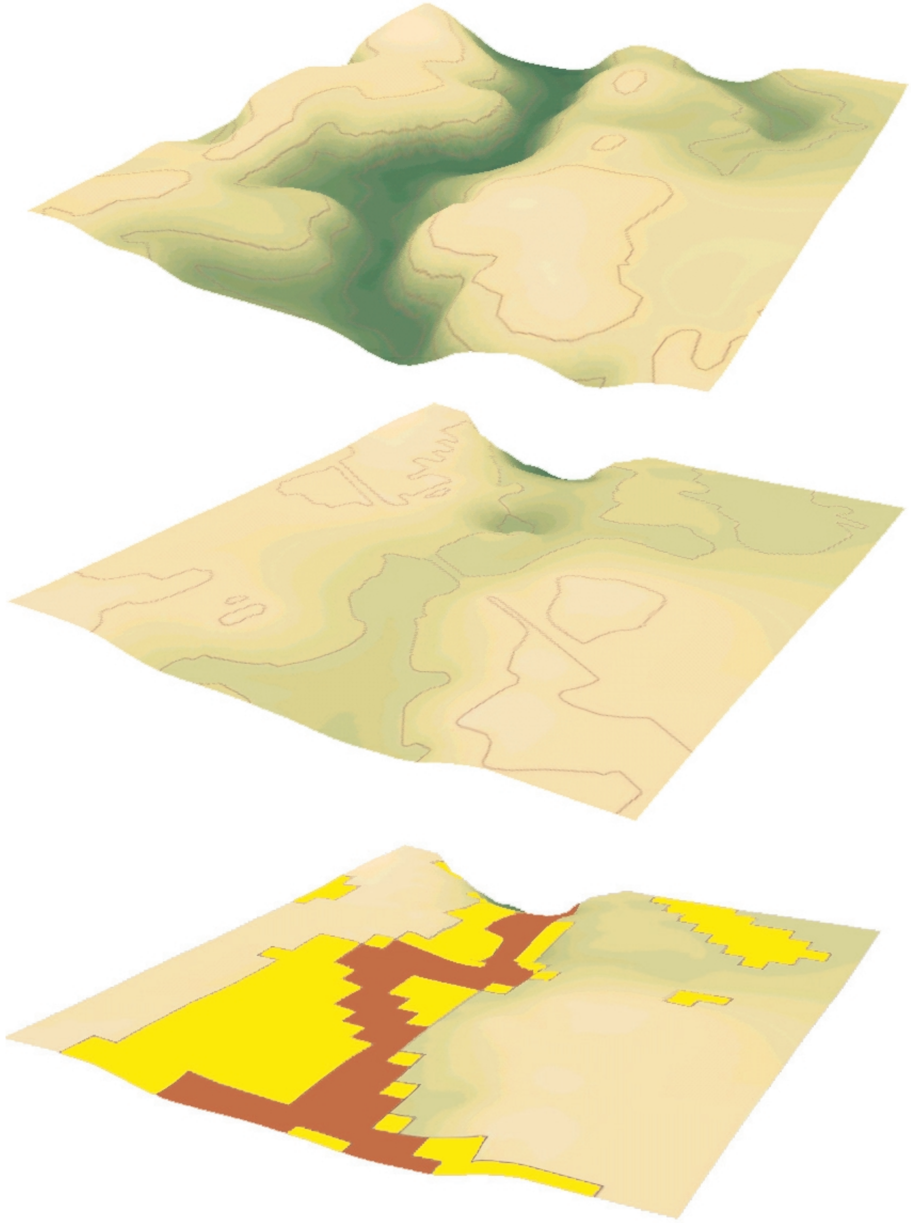
U. S. Department of the Interior
U. S. Geological Survey

Geographic Information System Analysis of Topographic Change in Philadelphia, Pennsylvania, During the Last Century

By
Peter G. Chirico and Jack B. Epstein

Open File Report 00-224

2000



OPEN FILE REPORT 00-224

Geographic Information System Analysis of Topographic Change in Philadelphia, Pennsylvania, During the Last Century.

By
Peter G. Chirico and Jack B. Epstein

2000

PREFACE

A scope of work was developed in response to a request by the U. S. Army Corps of Engineers, Philadelphia District. The request was to perform a topographic change grid analysis for the Frankford 7.5-minute quadrangle, 1:24,000-scale topographic map, which includes the Wissinoming neighborhood, and the Germantown 7.5-minute quadrangle, which includes the Logan and Feltonville neighborhoods of the City of Philadelphia. The following tasks were performed under this scope of work:

A GPS-corrected GIS grid analysis for each quadrangle was completed and is accompanied by documentation that describes procedures and provides metadata of the informational content of the GIS.

A high-resolution global positioning system (GPS) survey was conducted for each topographic quadrangle in order to evaluate and correct systematic discrepancies in elevation between the modern and historic surveys.

Prior to release, the fully documented GPS-corrected GIS grid analysis for each quadrangle was reviewed for (1) completeness of documentation and for (2) appropriate analysis and discussion of uncertainties.

The following report is in fulfillment of the tasks outlined in this scope of work and was performed by the U. S. Geological Survey for the U. S. Army Corps of Engineers, Philadelphia District under MIPR agreement number: W25PHS93358288.

INTRODUCTION

The U.S. Geological Survey (USGS), working in cooperation with the U. S. Army Corps of Engineers (ACOE), Philadelphia District, has conducted a study of topographic change throughout the Frankford and Germantown 7.5 minute USGS quadrangles, Philadelphia and Montgomery Counties, Pennsylvania and Burlington County, New Jersey. The purpose of this study is to determine the spatial extent of human-induced topographic change during the past 100 years. The USGS has conducted this study in response to severe structural damage and subsequent condemnation of houses within the Philadelphia city limits, due to differential subsidence of fill material within buried stream valleys.

Study Area

The topographic change mapping study encompasses the Frankford, Pennsylvania and New Jersey 7.5 minute quadrangle and the Germantown, Pennsylvania 7.5 minute quadrangle. These quadrangles cover approximately 114 square miles(296 square kilometers) of the northern part of the City of Philadelphia (Philadelphia County), the southeastern portion of Montgomery County and the northeastern portion of Burlington County, New Jersey (Figure 1).

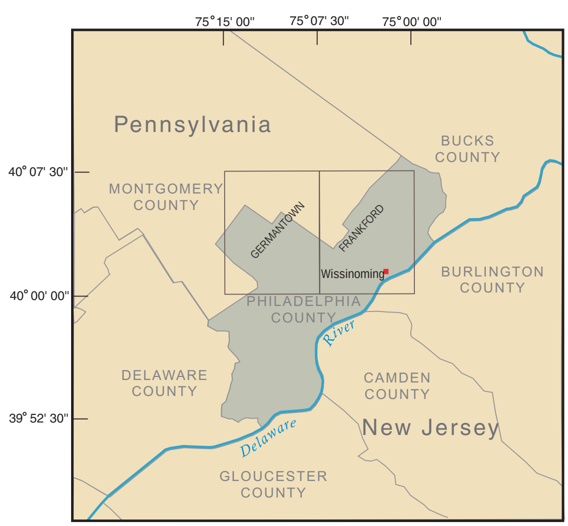


Figure 1. Study area index map showing current USGS topographic quadrangles and surrounding counties.

Background

There have been at least five separate incidents of a house or houses suffering structural damage and requiring condemnation in Philadelphia since 1931. During this time several people have been killed and more than 1,000 houses have had to be demolished. The most recent occurrence involved twenty five houses in the Wissinoming neighborhood of east-central Philadelphia.

It has been reported that the cause of the problem was and continues to be subsidence over stream valleys that have been improperly filled with coal ash and cinders (Philadelphia Inquirer, July 11, 1999). Historically, many tributary streams that flowed into the Delaware River were lined with storm sewers and the valleys were filled in with a variety of material, including the residue of the coal furnaces. Compaction of these materials and piping is a possible cause of the subsidence and ground failure.

This study involves a digital comparison of modern and historic spatial data collected from the USGS and the City of Philadelphia between 1888 and 1997. A geographic information system (GIS) was used to perform a grid analysis of topographic data from 1889 and 1997. Comparison of the two grids in conjunction with hydrographic and geologic data provides information on topographic and drainage modification in approximately 100 years of urban development. The results of this analysis are presented in a map depicting the spatial distribution of areas characterized as possible or probable fill.

Topographic change analysis to identify possible fill zones is composed of three primary steps. First, underlying geologic controls of the study area are considered. Second is a GIS comparison of a historic and current digital elevation model data. Third, the historic and current hydrography are modeled and included into the topographic change map. Each one of these factors is incorporated into the analysis, which is presented in the final map.

GEOLOGY

Philadelphia straddles two physiographic provinces, each with a distinct suite of rocks: the Atlantic Coastal Plain and the Piedmont. The Coastal Plain is a flat-lying area that is separated from the rolling topography of the Piedmont by the Fall Line. The Piedmont upland is traversed by many deep narrow stream valleys, many of which have been filled in since the turn of the century with old coal cinder and ash. Most of these valleys have eroded through the Coastal Plain sediments and exposed the underlying rocks of the Wissahickon Formation. Based on topographic maps published in 1899, prior to being filled in, these valleys averaged about 1,000 feet wide and ranged from depths as much as 60 feet in the Coastal Plain to more than 120 feet in the Piedmont.

The Coastal Plain comprises unconsolidated sediment deposits of Tertiary and Cretaceous age. These rocks dip gently to the southeast and thicken towards the Atlantic Ocean, exceeding 2,000 feet near the coast, but thin to a feather edge near the Fall Line in Philadelphia. They thicken to approximately 250 feet along the Delaware River in the map area. These sediments unconformably overlie much older, very complexly deformed rocks of the Piedmont province.

The Piedmont is divided into two parts, the Trenton Prong in the north and the Southern Piedmont (Figure 2); the boundary between the two parts is the Huntingdon Valley fault. The Trenton Prong contains Mesoproterozoic rocks and lower Paleozoic metasedimentary rocks, overlain at the extreme northwest corner of the map by Triassic sedimentary rocks. The Southern Piedmont contains schists, metagraywacke, amphibolite, and associated ultramafic rocks of the Wissahickon Formation of indeterminate (Cambrian to Late Proterozoic) age, overlain by unconsolidated Cretaceous and Tertiary sediments. The Proterozoic rocks are distinctly different in these two regions, suggesting that this fault may represent an important contact. The two terrains were probably joined before the Late Proterozoic or earliest Paleozoic. Both the northern and southern Piedmont are structurally complex, and are characterized by folded and imbricately stacked thrust faults and duplexes of probable Taconic age.

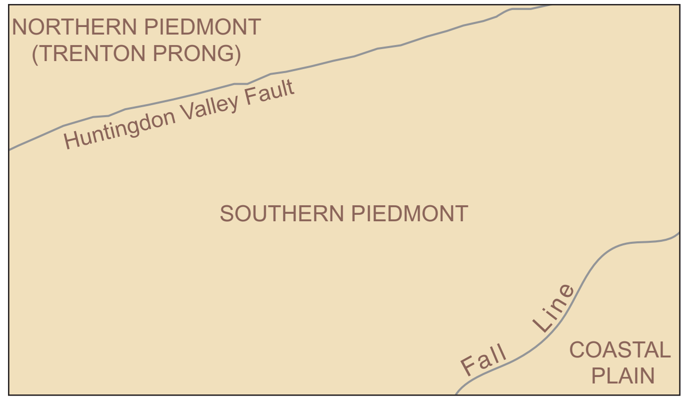


Figure 2. Physiographic and structural regions of the Frankford and Germantown quadrangles (from Lyttle and Epstein, 1987).

The geology of the area has been mapped in various degrees of detail by Bascom and others (1909), U.S. Geological Survey (1967a), Berg and others (1980), Berg and Dodge (1981), and Lyttle and Epstein (1987). These sources were used in the compilation of Plate 1, a Geologic map of the study area. Additional sources of information are listed in the "References" at the end of this report. Stratigraphic terminology has varied considerably among the several mappers in the Philadelphia area. Table 1 compares the various nomenclatures and the terminology used in this report.

Engineering characteristics of both Piedmont bedrock and Coastal Plain sediments, as well as cross sections across the Delaware River in the Philadelphia area showing surficial materials overlying bedrock are presented in U.S. Geological Survey reports on the engineering geology of the northeast corridor (1967a,b).

The creeks in the Philadelphia area generally flow to the southeast towards the Delaware River. This direction is controlled by the original southeastward dip of the coastal plain sediments. The creek valleys, however, are not straight; they have meanders with nearly right-angle bends. The directions that the creeks flow are controlled by the orientation of major fractures as shown by Goodwin (1963).

Bascon and others, 1909	Berg and Dodge, 1981	Lyttle and Epstein, 1987	This report
Qcm Cape May formation	**Qt** Trenton Gravel		**Qt** Trenton gravel of Lewis (1880)
Qpd Pensauken formation	**Tpb** Pensauken and Bridgeton Formations, undiff		**Tpb** Pensauken and Bridgeton Formations, undiff
Tl Lafayette formation	**Tbm** Bryn Mawr Formation		**Tbm** Bryn Mawr Formation
Kpt Potapsco formation	**Kp** Potapsco(?) Formation		**Kp** Potomac Formation
diabase dikes	**Trd** Diabase	metadiabase dikes	**Jd** Diabase
Trs Stockton formation	**Trs** Stockton Formation	**Trs** Stockton Formation	**Trs** Stockton Formation
pt pegmatite	**Xpg** Pegmatite		**Op** Pegmatite
grn Granite gneiss	**Xgr** Granitic gneiss and granite	**Osg** Swarthmore Granodiorite	**Osg** Swarthmore Granodiorite
os Shenandoah limestone	**Oc** Conestoga Formation	**Oc** Conestoga Limestone	**Oc** Conestoga Limestone
os Shenandoah limestone	**e** Elbrook Formation	**e** Elbrook Formation	**e** Elbrook Formation
os Shenandoah limestone	**l** Ledger Formation	**lg** Ledger Dolomite	**l** Ledger Dolomite
c Chickies quartzite	**ch** Chickies Formation	**c** Chickies Quartzite	**c** Chickies Quartzite
hgn Hornblende gneiss	**Xmgh** Mafic gneiss, hornblende-bearing	**za** Amphibolite	**za** Amphibolite
sp Metapyroxenite and metaperidotite	**Xs** Serpentinite	**zs** Serpentinite	**zs** Serpentinite
wg Wissahickon mica gneiss	**Xw** Wissahickon Formation	**zw** Wissahickon Formation	**zw** Wissahickon Formation
hgn Hornblende gneiss	**mgh** Mafic gneiss, hornblende-bearing	**Ya** Amphibolite	**Ya** Amphibolite
bgn Baltimore gneiss	**fgp** Felsic Gneiss, pyroxene-bearing	**Ymg** Amphibolitic migmatite and related hybrid rocks	**Ymg** Amphibolitic migmatite and related hybrid rocks

Table 1. Table showing stratigraphic nomenclature and terminology in previous publications and those used in this report.

TOPOGRAPHIC CHANGE ANALYSIS

Recent advancement in mapping technology have enabled many researchers to use GIS as a tool for mapping topographic change. The Airborne Topographic Mapper (ATM), a scanning LIDAR altimeter combined with a kinematic Global Positioning System (GPS), is capable of producing a high-resolution digital elevation model (DEM) with a horizontal cell size less than a meter. A GIS comparison of high resolution DEM's of a particular area can provide highly accurate horizontal and vertical topographic change information. This method of remote sensing has proven powerful when mapping features susceptible to constant change such as beaches and sand dunes (Irish and Lillycrop, 1999), and glacial surfaces and sea ice (Krabill and others, 1999). Little work has been done in urban areas to determine topographic change with the ATM due to the complications associated with buildings and urban land cover.

Changes in topography that occur over a long period of time, or prior to the availability of remote sensing platforms, have been determined through qualitative and quantitative interpretations of historic topographic maps. Hodgson and Alexander (1990, p 110.) explained that "historic depiction of topography may in some cases reveal significant geomorphic or humancaused modification". They also assert that new GIS methods need to be developed in inventory or change detection studies to account for the positional and attribute compatibility of these historic data sets.

Past studies have identified errors associated with comparing modern and historic topographic data. Butler (1989) directed research towards comparing historic topographic map data throughout Glacier National Park in support of geomorphic change mapping. His research concluded that gross topographic inaccuracies depicted in the historic map data used should prevent drawing conclusions of geomorphic processes from such comparisons, especially where elevations are concerned. In a response to Butler's conclusion, Morrison (1990) concedes the limitations of plane table mapping efforts of the historic topographers, but also reviews the issue of comparing data from different map scales. To avoid the errors that Butler encountered, with respect to map scale and accuracy, a thorough explanation of the source data used in this study and a discussion of historic and current mapping techniques is presented.

Historic Topographic Contour Data

The historical USGS topographic quadrangle that covers the study area is the 1899 Germantown 1:62,500 scale quadrangle with a 20 foot contour interval (Figure 3). The topographic data presented on this map were constructed using the plane table surveying method, whereas recent topographic information is mapped using aerial photography. The accuracy of the plane table survey relied on a variety of factors including the landscape, distance from benchmark control, and mapping scale.

Landscape

Hypsographic contour lines are calculated from a triangulated network of points representing surveyed locations and their elevations. Topographic engineers mapped along straight line traverses from benchmark control points to establish a network of triangulated positions. The landscape determines where crews are able to map traverses. Detailed topographic relief can be difficult to map in areas highly dissected by streams with high bluffs (Beaman, 1928). If areas are not open and free from tree cover, traverses typically are run along ridges or streams. Trigonometric calculations provide intermediate elevations between surveyed locations. Lines connecting points of equal elevation are hand drafted in the field and are based on the mathematical data and field observations. If the terrain inhibits the ability to perform optimum traverses a reduction in detail or accuracy often results.

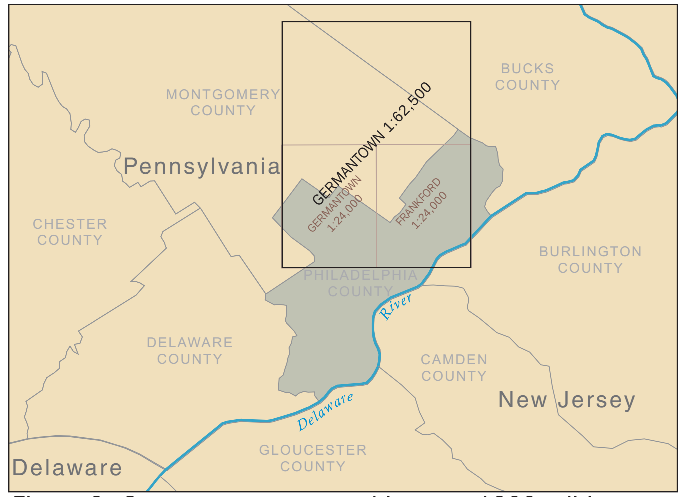


Figure 3. Germantown topographic map, 1899 edition 1:62,500 scale showing current 1:24,000 scale maps for the study area.

Benchmark Control

Traverses were mapped starting at benchmark control monuments within the quadrangle area. The potential of error in calculated elevation data within a traverse increases the farther a survey crew proceeds from a benchmark. Therefore, the location of benchmarks used for the historic survey is significant in understanding the parameters under which the original survey was conducted. Vertical and horizontal control points along railroad lines provided primary triangulation benchmarks for early surveys. Benchmark control for the 1889 survey ran along the New York division, the Schuylkill division and the Philadelphia, Germantown and Chestnut Hill branch of the Pennsylvania Railroad (Marshall, 1912). Geodetic benchmarks for the survey of the Germantown quadrangle were originally measured by the U.S. Coast and Geodetic Survey and the City of Philadelphia. The stations and elevations used for the original survey are included in Table 2 and a map showing the approximate locations of these control points is shown in Figure 4.

Figure 4. Approximate locations of historic control points. Station numbers correspond to those shown in Table 2. P.R.R. 68, P.R.R. 7 and P.R.R. 8 have been omitted from the map because they fall outside the map area.

Scale

E. W. F. Natter completed the original survey of the Germantown 15-minute topographic quadrangle in the 1889 field season (Gannett, 1889). However, engraving and eventual publication did not occur until 1899. Later revisions updated cultural features leaving the original hypsographic contours unrevised until the 1950's. The scale of Natter's 1889 survey and compilation was at 1:45,000-scale, although the map was published at the scale of 1:62,500 (Gannett, 1889).

Current Topographic Contour Data

Two 7.5-minute USGS topographic quadrangles (Frankford, Pennsylvania and New Jersey, 1997 with a 20 foot contour interval and Germantown, Pennsylvania, 1997 with a 10 foot contour interval) were used to furnish hypsographic contours for the current data set. These contours were created through the

STATION NAME	NUMBER	CONTROL ELEVATION
NEW YORK DIVISION		
Torresdale	P.R.R. 68	35.90
Pierson	P.R.R. 69	34.11
Holmesburg Junction	P.R.R. 70	26.39
Holmesburg Junction	P.R.R. 71	35.04
Tacony	P.R.R. 72	33.07
Wissinoming	P.R.R. 72a	30.70
Bridesburg	P.R.R. 73	34.94
Frankford	P.R.R. 74	32.68
Harrowgate	P.R.R. 75	49.54
North Penn	P.R.R. 76	102.44
SCHUYLKILL DIVISION		
Manayunk	P.R.R. 4	90.27
Shawmont Avenue	P.R.R. 5	97.32
Philadelphia	P.R.R. 7	73.23
Spring Mill	P.R.R. 8	56.80
PHILADELPHIA, GERMANTOWN AND CHESTNUT HILL BRANCH		
Allen Lane	P.R.R. 608	317.72
Wissahickon Heights	P.R.R. 609	336.99
Highland	P.R.R. 610	391.63
Chestnut Hill	P.R.R. 611	424.18

Table 2. Historic benchmark contol points along rail lines throughout study area. See Figure 4 for locations.

photogrammetric processes outlined in the USGS Topographic Instructions publications (Loud, 1952). Major factors influencing the creation of modern hypsographic contour data include quality of aerial photography, benchmark control, and skill of the stereo plotter operator.

Mapping through the use of aerial photographs has largely replaced field surveys for topographic mapping. Aerial photographs in stereographic sets are used in association with a device called a stereo plotter. Photographs used with the stereo plotter usually have about 60 percent overlap along the line of flight (Avery and Berlin, 1985). Photographs viewed through a stereo plotter develop a three-dimensional model of the area of overlap. The three-dimensional model of the map area is developed using ground control points collected in the field, which provide known locations of elevation. Variations in photographs due to aircraft flight characteristics, which include crab, drift, and tilt, are corrected and accounted for in setting up the stereo model. Several sets of aerial photographs need to be matched together to provide enough data for mapping an entire quadrangle.

Benchmark Control

Control points for the current Frankford and Germantown topographic quadrangles were surveyed by the USGS, the Coast and Geodetic Survey, and the City of Philadelphia and were used for the stereo plotter setup. These benchmarks are dispersed throughout the map area to account for distortions in the aerial photographs and to provide the best baseline elevations.

Photogrammetry

The stereo plotter allows a user to trace features seen in the three-dimensional view from aerial photographs. Skill is required to trace features using these manual stereo compiling machines. Successive advances in photogrammetric compilation equipment have made it easier for operators to trace information from stereo models. Traced features are later scribed onto separate map layers which form the basis for the printed map. A different map layer for each set of features is created. Examples of map layers include roads, railroads, hydrographic features, buildings and hypsographic contours.

Digitization of Historic and Recent Topography

USGS staff and contractors scanned and vectorized map layers for the historic and current topographic contour lines. Map separates were scanned by a high-resolution large-format scanner, vectorized, and imported into the GIS where they were edited and attributed.

GPS Control Points

A high-resolution global positioning system (GPS) survey was conducted for 21 points throughout the study area to assess systematic discrepancies in both historic and current digital elevation model data. GPS control points were collected using two Trimble Pro XRS GPS units under the carrier phase recording capability (Figure 5). Positions were post processed and differentially corrected to the New Jersey Department of Environmental Protection (NJDEP) base station located in Trenton, New Jersey. This correction provides the highest possible vertical accuracy. Points were collected in undeveloped areas, avoiding locations that may have experienced human induced topographic change in the last 100 years. The GPS points collected by the USGS were combined with 26 survey ground elevation data points provided by the City of Philadelphia.
The 47 ground elevation data points formed the control data set (Figure 6). The comparison of control points to elevations was used to determine the relative accuracy of the historic and current hypsography.

Figure 5. GPS control point data collection.

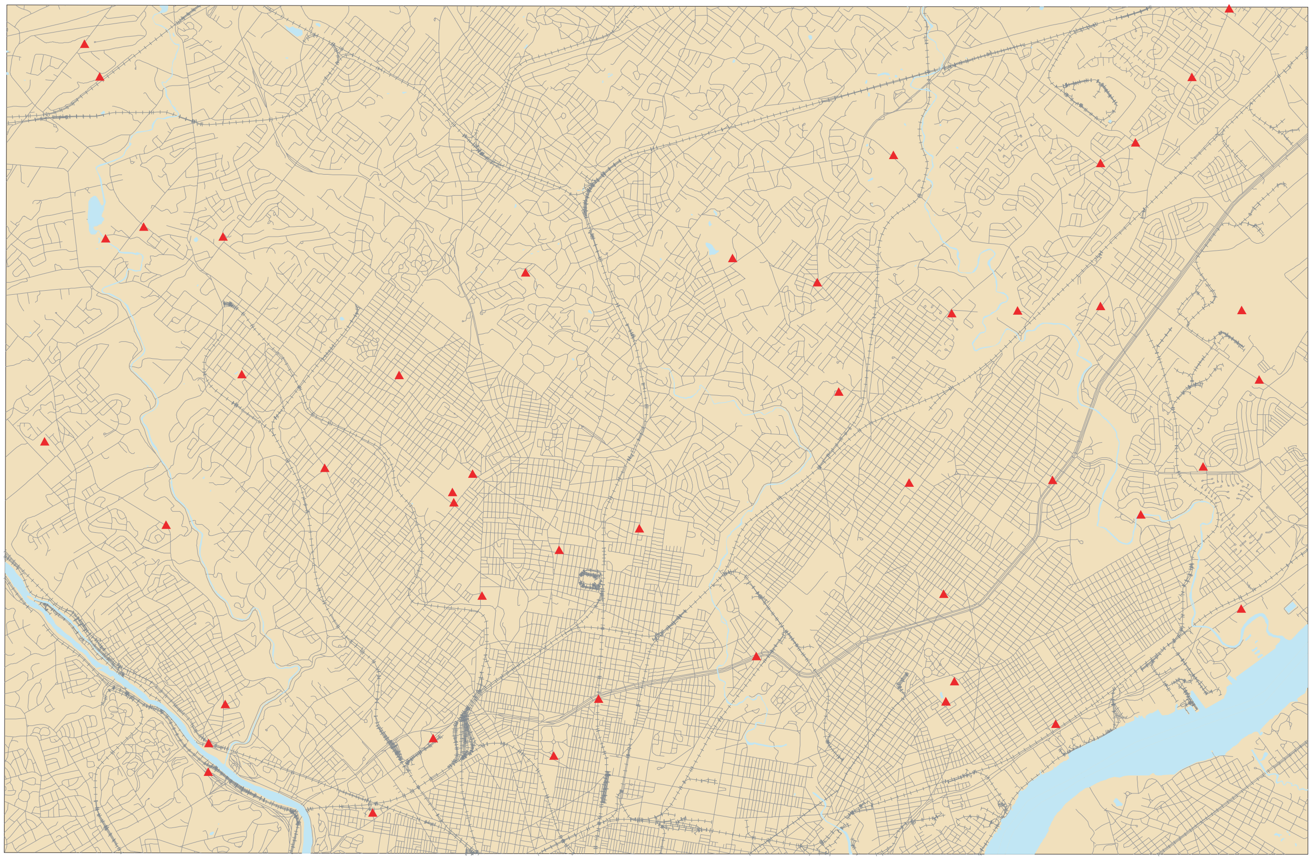


Figure 6. Locations of USGS and City of Philadelphia ground elevation GPS control points.

Explanation of Spatial Correction of Historic Topographic Data

GIS analysis of control point locations detected vertical accuracy discrepancies in the historic topographic data set. Large differences in elevation between the GPS control points and their corresponding locations in the historic data set indicated misrepresentation of topography.

Figure 7 shows an example of horizontal positioning error in the historical map data and the method used to correct it. The current DEM displays general topographic relief in shades from green to brown. Overlying the current DEM, in black line work, are the historic contours for the same area. The line drawn in blue represents the current thalweg of the stream valley (line of greatest slope along the valley floor) and in red is a line that shows the historic thalweg of the same valley. The historic contour data, in this example, varies in its representation of the valley from the expected location as defined by the shaded DEM. Points representing the location of thalweg intersections and height values along prominent contour lines are used to create linkages between the current and historic data features. Several hundred links were added to the historic coverage in areas of greater topographic relief in the western and northern parts of the study area where horizontal discrepancies were noted. Once all links were established, a localized stretch and fit function was used in the GIS to improve correlation of topographic highs and lows represented on both topographic data sets. Figure 8 shows an example of the results of this localized stretch and fit.

Topographic Change Methodology

The comparison of elevation data was done by first creating a digital elevation model (DEM) grid for each digital hypsography coverage. The values in the historic DEM were then subtracted from the current DEM. The product of this comparison is an output grid with

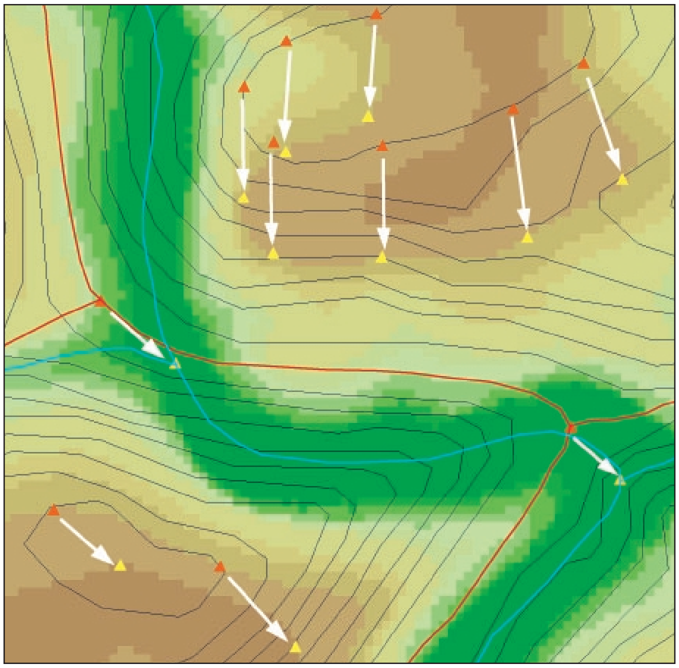


Figure 7. Example of localized fit adjustments made to historic hypsography data. Arrows indicate direction of correction according to thalweg and ancillary elevation points

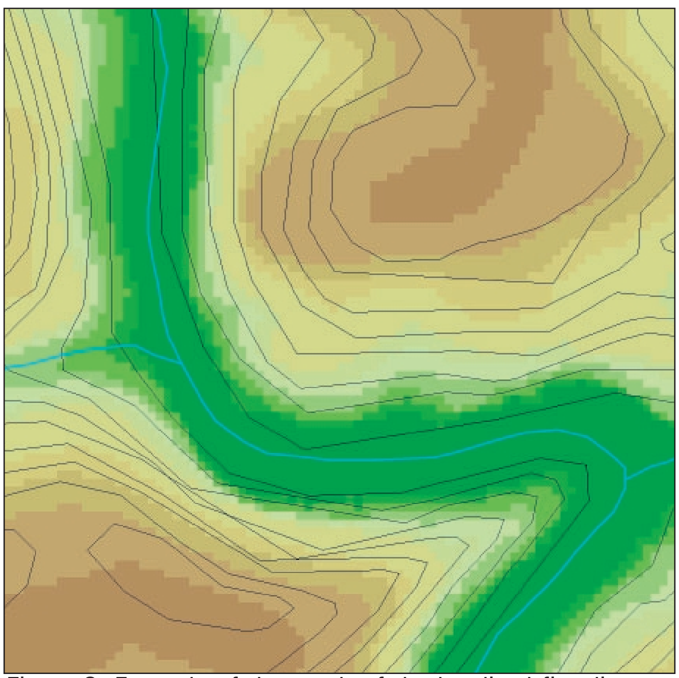


Figure 8. Example of the result of the localized fit adjustment. Contour lines of historic data conform to modern topographic relief features shown in color.

values representing the difference in topography, either positive, negative, or no change (Figure 9). The GPS control points were again used to determine how accurately the interpolated DEM resembles the true topographic relief.

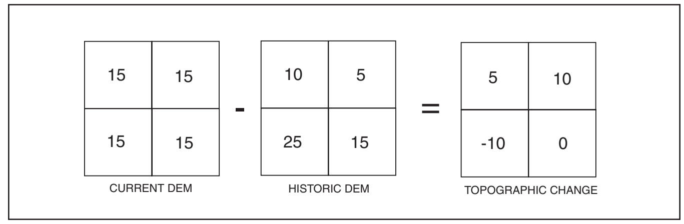


Figure 9. Example of topographic change grid created from historic and current DEM data.

DEM Interpolation

The corrected historic contour data and the current contour data were used as inputs to the TOPOGRID command (ArcInfo GIS software) to produce viable DEM's. The TOPOGRID command uses an updated variation of the ANUDEM algorithm developed by Hutchinson (1989, 1996). In this technique, the gridding algorithm interpolates input elevation values from contour data and outputs a raster grid. Each grid cell is attributed with an elevation value. A 50 meter by 50 meter grid cell size was used for the interpolation of both the historic and current DEM's. Both the scale of the input data (1:62,500 and 1:24,000) and the difference in contour intervals across the current map quadrangles were considered in selecting the 50 meter cell size for the output grid. A 50 meter grid cell is appropriate for the regional level of analysis used in this study and should not be used for site-specific examination.

Interpolated data from the DEM's was compared to the GPS control points to develop an accuracy index of DEM to true landscape. The complete table showing the control and DEM elevations is provided in Table 3. The mean difference of the control to the current DEM was 6.11 feet. The mean difference between the control and the historic DEM, was 9.13 feet. The current elevation data varied by a maximum of 21.03 feet and the historic elevation data varied by a maximum of 43.03 feet. The comparison of values helped to provide a confidence interval for the resulting grid analysis as well as targeting areas in the historic DEM where spatial correction was needed

Calculation of Topographic Change

The topographic change component of the model is a product of subtracting the historic DEM data values from the current DEM data values (Figure 9). The

STATION NAME	SOURCE	EASTING	NORTHING	CONTROL ELEVATION	1997 DEM	1997 VARIANCE VALUE	1899 DEM	1899 VARIANCE VALUE
Hunting Park	USGS	487696.16	4429390.00	123.72	119.96	3.76	119.24	4.48
Wister Woods	USGS	486517.06	4432013.00	219.80	206.12	13.67	217.96	1.84
Awbury Rec	USGS	486034.72	4433704.50	289.93	285.64	4.29	284.58	5.34
Dom Benchmark	USGS	492008.09	4437145.00	231.50	234.33	2.83	236.66	5.17
Wiss Park1	USGS	494254.88	4430611.50	83.13	73.96	9.18	69.83	13.30
Little Pennypack Park	USGS	498328.75	4434124.50	77.72	78.45	0.72	100.87	23.15
Pennypack Park Verree	USGS	494209.91	4436635.50	153.70	154.51	0.81	162.38	8.68
Holy Redeemer Church	USGS	493254.16	4439223.00	245.23	243.71	1.52	230.49	14.74
Curtis Manor	USGS	487231.66	4437301.00	327.92	325.79	2.13	314.91	13.00
Ft. Washington 1	USGS	480013.84	4441042.50	342.67	324.53	18.15	332.00	10.68
Upenn Arboretum	USGS	480353.94	4437857.00	132.55	130.54	2.01	140.00	7.45
Awbury Rec2	USGS	486054.53	4433538.50	259.94	261.22	1.28	257.94	2.00
Whitemarsh Jr. High	USGS	482281.81	4437892.00	234.87	246.09	11.22	203.80	31.07
Pastorius Park	USGS	482587.50	4435639.00	357.79	356.56	1.22	368.65	10.86
Alverthorpe Park	USGS	490617.94	4437540.50	256.64	252.75	3.88	262.27	5.63
Wiss Park 2	USGS	494113.53	4430281.00	53.27	59.38	6.11	60.00	6.73
Disston Park	USGS	495911.63	4429914.50	39.17	22.71	16.45	35.69	3.48
Pennypack Park Creek	USGS	497306.19	4433339.50	30.16	40.16	10.00	42.36	12.20
Mnt. Police Hdqt.	USGS	495288.97	4436682.00	159.81	142.51	17.30	156.01	3.79
Ft. Washington 2	USGS	480263.50	4440510.50	171.65	169.73	1.92	169.73	1.91
academy	CITY	499241.94	4435548.50	121.25	104.35	16.90	103.51	17.74
adams	CITY	491012.72	4431025.00	105.45	104.01	1.44	102.86	2.59
allegheny	CITY	484726.78	4428464.00	130.40	114.02	16.38	110.01	20.39
ash	CITY	498953.06	4431799.50	24.70	20.22	4.48	20.45	4.25
bvm	CITY	496646.16	4436755.50	143.10	135.33	7.77	133.25	9.85
bluehead	CITY	498752.44	4441625.50	221.55	220.00	1.55	213.41	8.14
burgess	CITY	498144.59	4440502.50	224.20	222.30	1.90	222.03	2.17
burholme	CITY	492357.41	4435348.50	209.90	195.12	14.78	200.43	9.47
champlost	CITY	487780.75	4432760.00	213.50	210.11	3.39	217.33	3.83
cityline	CITY	482035.56	4429131.50	122.75	109.94	12.81	104.94	17.81
fernhill	CITY	485720.59	4429677.50	172.10	151.06	21.04	129.07	43.03
henry	CITY	481343.94	4433174.50	291.40	291.20	0.20	293.77	2.37
jardel	CITY	493512.50	4433862.00	135.10	135.04	0.06	135.39	0.29
king	CITY	486364.00	4434009.00	268.15	268.16	0.01	259.52	8.63
leeds	CITY	485159.19	4435625.50	344.55	349.37	4.82	354.93	10.38
loney	CITY	495859.03	4433905.50	105.65	104.61	1.04	111.80	6.15
max	CITY	494078.19	4432045.00	110.30	101.13	9.17	100.45	9.85
morefield	CITY	496642.78	4439094.50	189.70	190.43	0.73	185.17	4.53
oaklane	CITY	489098.47	4433110.00	218.60	220.12	1.52	218.23	0.37
righter	CITY	482318.06	4430235.50	258.60	252.19	6.41	245.84	12.76
sedgwick	CITY	483944.63	4434102.50	346.25	352.15	5.90	356.57	10.32
stenton	CITY	480979.16	4438054.50	141.25	142.78	1.53	140.17	1.08
sunset	CITY	479358.47	4434540.00	423.80	420.65	3.15	425.04	1.24
verree	CITY	497218.38	4439429.50	188.70	186.59	2.11	180.99	7.71
wyoming	CITY	488426.78	4430327.50	131.40	116.42	14.98	111.16	20.24
arp	CITY	498956.59	4436685.50	106.78	103.51	3.27	99.33	7.45
f1	CITY	482044.16	4429598.50	88.05	86.54	1.52	86.82	1.24

Table 3. Values of the control point elevations, historic, and current interpolated DEM values.

resulting grid shows topographic change for every cell in the study area. Values are either positive, negative or zero. Positive values show fill, negative values show removal, and zero indicates no change.

Hydrography

Historic streams, shown on maps of the City of Philadelphia and the USGS Topographic maps, are modeled to aid in assessing areas showing possible fill. Two different data sets were combined in the GIS to provide a data layer of historic streams. The first data set, provided by the ACOE, are of buried streams from within the Philadelphia city limits. Streams are shown in great detail and are derived from City of Philadelphia Water Department historic surveys and records. Hydrography from the 1899 Germantown quadrangle was used to augment this data set for areas outside the city. The 1899 Germantown coverage of streams was edited to retain only streams that appeared in the historic data set, but no longer appear on subsequent maps. The combination of these two historic streams layers formed a historic stream coverage for the entire study area.

Measurements from the GIS data of the study area yielded an average width of 50 meters on either side of a stream for the active stream channel of creeks and streams. Buffering the historic streams coverage by 50 meters in the GIS creates a map layer that represents the immediate channel of the streams. This buffer feeds into the grid algorithm outputting a grid that represents the stream channel of the historic streams.

Final Grid Analysis

Map grids representing topographic change and historic stream channels were combined to define areas of fill. The results of the analysis show two types of grid cells: One representing possible fill and the other representing probable fill. Possible fill is defined as an area where either there is positive topographic change *or* the historic streams coverage indicated a historic stream channel or low area that no longer exists. Probable fill is defined as an area where the topographic change method *and* the historic stream coverage indicate both the presence of a historic stream channel and positive topographic change. The results of the grid analysis showing the possible and probable spatial extent of filled in stream valleys and topographically low areas is provided in Plate 2.

The study of historic topographic change presented here utilizes a different methodology than that used in previous studies of topographic change. In light of the previous complications in assessing historic topographic change, actual depth of fill is not attempted in this study. In addition, a larger scale historic map is used and significant research has documented possible error propagation in both the historic and current data set.

Topographic comparisons between historic data and current data are done with caution, and with a thorough understanding of the inaccuracies that may develop. These inaccuracies have been addressed to provide the user of these data with a complete understanding of the limitations of drawing conclusions from such a study.

GUIDE TO INTERPRETATION OF THE TOPOGRAPHIC CHANGE MAPS

Plate 2 shows the results of the topographic change grid analysis presented above. The map shows a unique distribution of both possible and probable fill zones throughout the study area. Zones designated as possible or probable fill do not imply the occurrence of structural subsidence. The map does not show the depth of possible or probable fill, the origin or composition of the fill material or any engineering characteristics of sites located in or near fill areas. Rather, the map should be interpreted as an indication of areas that may have been physically modified through 100 years of Philadelphia's urbanization.

General trends shown in the fill map reflect linear features such as stream valleys and transportation infrastructure. Several historic stream valleys can be discerned in the map, including those for Wissinoming Creek, Little Tacony Creek and Wingohocking Creek. Other smaller creek beds and topographically low areas are apparent as well. Transportation features such as rail lines and interstate highways tend to coincide with fill areas. Graded slopes are important for the construction of roads and railroads and there may be a correlation with fill shown along these features. Interstate I-95, shown in the south eastern part of the study area, is an example of a transportation feature which shows possible fill located along its route.

Further studies using the map and analysis presented in this report should be undertaken. Investigations of particular areas of interest and their historical development would prove beneficial to explaining the spatial distribution of topographic change associated with urbanization.

REFERENCES

Avery, T. E., and Berlin, G. L., 1985, Interpretation of aerial photographs, New York, 554 p.

Amenta, R.V., Crawford, M.L., Crawford, W.A., Fergusson, W.B., Parrott, W.R., Jr., Roberts, F.H., Trojan, E.J., and Wagner, M.E., 1974, Field conference of Pennsylvania geologists, 39th Geology of the Piedmont of southeastern Pennsylvania: Harrisburg, Pa., Pennsylvania Geological Survey, 104 p.

Bascom, Florence, Clark, W. B., Darton, N. H., Kummel, H. B., Salisbury, R. D., Miller, B. L., and Knapp, G. N., 1909, Description of the Philadelphia District: U.S. Geological Survey Geologic Atlas, Folio 162, 24 p.

Beaman, W. M., 1928, Topographic Instructions of the United States Geological Survey, E. Topographic Mapping, U.S. Geological Survey Bulletin 788-E, 378 p.

Berg, T. M., and Dodge, C. M., 1981, Atlas of preliminary quadrangle maps of Pennsylvania: Pennsylvania Geological Survey, 4th series, Map 61, 636 p.

Berg, T. M., and others, 1980, Geologic map of Pennsylvania: Pennsylvania Geological Survey, 4th series, scale 1:250,000.

Butler, David R., 1989, Geomorphic change or cartographic inaccuracy? a case study using sequential topographic maps, Surveying and Mapping, v. 49, n. 2, pp. 67 -71.

Ferguson, W. B.; Glynn, E. F., 1988, A foundation failure in Philadelphia: in Prakash, Shamsher, ed., Second international conference on Case studies in geotechnical engineering; proceedings, v. 2, p. 1293-1296.

Gannett, Henry, 1889, Administrative Reports, in Tenth annual report of the United States Geological Survey to the Secretary of the Interior 1888-1889, by J.W. Powell, director, Part 1 - Geology, pp. 83-88.

Goodwin, B.K., 1963, Structural control of Wissahickon Creek in Philadelphia, Pennsylvania: Proceedings of the Pennsylvania Academy of Science, v. 37, p. 304-308.

Goodwin, B.K., 1964, Guidebook to the geology of the Philadelphia area: Pennsylvania Geological Survey, 4th series., Bulletin G 41 (General Geology Rept.), 189 p.

Hodgson, Michael, E., and Alexander, Robert, H., 1990, Use of historic USGS topographic maps in GIS analysis: Technical Papers of the American Congress of Surveying and Mapping, v. 3, p. 109-116.

Hutchinson, M.F., 1989, A new procedure for gridding elevation and stream line data with automatic removal of spurious pits, Journal of Hydrology, v. 106, pp 211-232.

Hutchinson, M.F., 1996, A locally adaptive approach to the interpolation of digital elevation models, In Proceedings: Third International Conference/Workshop on integrating GIS and Environmental Modeling, Sante Fe, NM, January 21-26.

Irish, J.L., W.J. Lillycrop, 1999 "Scanning Laser Mapping of the Coastal Zone: The SHOALS System", ISPRS Journal of Photogrammetry & Remote Sensing , Vol. 54, Nos. 2-3, pp. 123-129.

Krabill, W., Frederick, E., Manizade, S., Martin, C., Sonntag, J., Swift, R., Thomas, R., Wright, W., and Yunge, J., 1999, Rapid thinning of parts of the southern Greenland ice sheet: Science, Mar. 5, pp 1522-1524.

Lewis, H.C., 1880, The Trenton gravel and its relation to the antiquity of man: Academy Natural Sciences of Philadelphia Proceedings, p. 296-309.

Loud, Edward, I., 1952, Topographic Instructions: book 3, part 3C, photogrammetric mapping: chapter 3C7a-e, multiplex procedure: U.S. Geological Survey Circular, 164.

Lyttle, P.T., and Epstein, J.B., 1987, Geologic map of the Newark 1 X 2 quadrangle, Pennsylvania, New Jersey, and NewYork: U.S. Geological Survey Miscellaneous Investigations Series Map, 1-1715 1:250,000.

Marshall, R. B., 1912, Results of spirit leveling in Pennsylvania 1899 to 1911, inclusive: U.S. Geological Survey Bulletin, 515.

Morrison, Joel, L., 1990, Geomorphic change or cartographic inaccuracy? a case study using sequential topographic maps; discussion, Surveying and Land Information Systems, v. 50, p. 50.

Owens, J.P., 1999, Cretaceous and Tertiary, in Shultz, C.H., ed., The Geology of Pennsylvania, Part II. Stratigraphy and Sedimentary Tectonics, Pennsylvania Geological Survey, Harrisburg, and Pittsburgh Geological Society, Pittsburgh, p. 218-223.

Owens, J. P. and Minard, J.P., 1979, Upper Cenozoic sediments of the lower Delaware Valley and the northern Delmarva Peninsula, New Jersey, Pennsylvania, Delaware, and Maryland: U.S. Geological Survey Professional Paper 1067-D, 47 p.

Owens, J. P., and Sohl, N. F., 1969, Shelf and deltaic paleoenvironments in the Cretaceous-Tertiary Formations of the New Jersey Coastal Plain, in Subitzky, Seymour, editor, Geology of selected areas in New Jersey and eastern Pennsylvania: Rutgers University Press, Brunswick, New Jersey, p. 235-278.

Paulachok, G.N., 1991, Geohydrology and groundwater resources of Philadelphia, Pennsylvania: U.S. Geological Survey Water-Supply Paper 2346, 79 p.

Rima, D. R., Neisler, Harold, and Longwill, Stanley, 1962, Geology and hydrology of the Stockton Formation in southwestern Pennsylvania: Pennsylvania Geological Survey, 4th series, Groundwater Report W14, 111 p.

U.S. Geological Survey, 1967a, Engineering geology of the Northeast Corridor, Washington, D.C., to Boston, Mass.: Bedrock Geology: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-514-B.

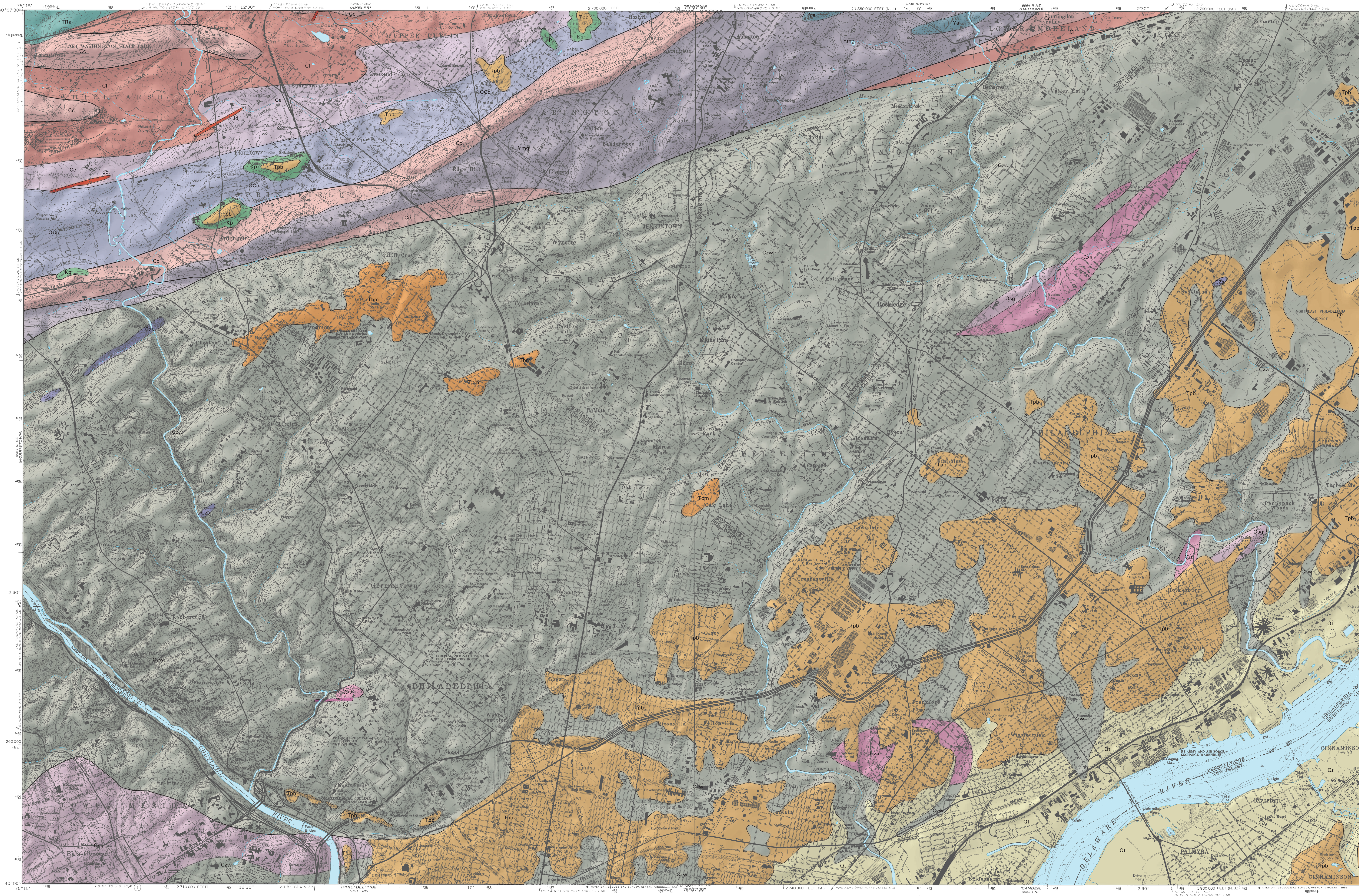
U.S. Geological Survey, 1967b, Engineering geology of the Northeast Corridor, Washington, D.C., to Boston, Mass.: Coastal Plain and surficial deposits: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-514-B.

Weiss, Judith, 1949, Wissahickon Schist at Philadelphia: Geological Society of America Bulletin, v. 60, p. 1689-1726.

U. S. DEPARTMENT OF THE INTERIOR
U. S. GEOLOGICAL SURVEY

Prepared in Cooperation with the
U. S. ARMY CORPS OF ENGINEERS

OPEN-FILE REPORT 00-224
PLATE 1



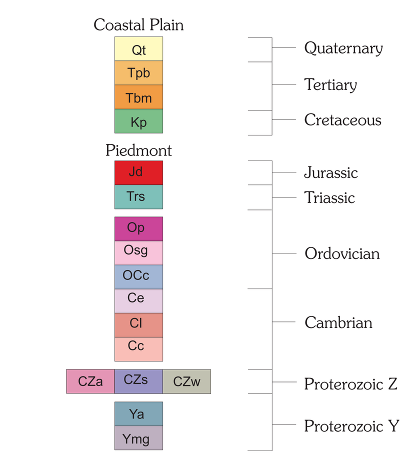
Base from U.S. Geological Survey Digtial Raster Graphics (DRG's) of Frankford, 1997 and Germantown,1997.

North American Datum of 1927 (NAD 27)
Projection: Universal Transverse Mercator (UTM), zone 18

Geologic map compiled by J. B. Epstein. Adapted from Bascom and others (1909), U.S. Geological Survey (1967a), Berg and others (1980), Berg and Dodge (1981), and Lyttle and Epstein (1987).

Digital Cartography by S. Hinman and P.Chirico.

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

Qt — **Trenton gravel of Lewis (1880) (Pleistocene) -** Interbedded, cross-bedded sand and gravel with oblate pebbles and cobbles, and local clay and silty clay. Rare large boulders several feet long in places. Ranges in thickness from a feather edge at the northwestern contact to more than 100 feet. Forms a terrace which rises to about 60 feet above the Delaware River at the Tacony Bridge, where the unit is about 120 feet thick (Owens and Minard, 1979). The pebbles are derived from Triassic red and gray shales, sandstones, and conglomerate, and other bedrock up-valley. Human artifacts (Lewis, 1880) suggest an age no greater than about 11,000 years for part of the unit, although Owens and Minard (1979, p. D38, D42) suggest a Sangamon age of approximately 100,000 years for their "Spring Lake beds" and younger "Van Sciver beds" of the "Trenton gravel". The unit is therefore probably a combination of Wisconsinan glacial outwash and older interglacial estuarine sediments. These sediments were incorrectly identified as the Potomac Group by the U.S. Geological Survey (1967b); Owens (1999) mapped the Potomac Group at much higher altitudes and approximately 10 miles north of the river.

Tpb — **Pensauken and Bridgeton Formations,** Undifferentiated (Tertiary, Miocene) - Interbedded yellow, white, to reddish, commonly iron-stained, planar- to cross-bedded, variably sorted sand and gravel with minor clay and silt. Gravel may be cobbly and contain rare boulders as much as 6 feet long. Pebbles are mostly quartz, chert, and quartzite pebbles; granite and gneiss are less common, and shale, arkosic sandstone and diabase even less. The sand comprises predominantly quartz, with weathered feldspar, glauconite, and iron oxide as minor constituents. May be moderately cemented with iron oxide. Thickness reaches 50 feet in Philadelphia, but it is generally much less than that. The Pensauken and Bridgeton Formations, undifferentiated, form dissected flat terraces that rise from about 60 feet altitude, where it is in contact with the Trenton gravel, to about 120 feet in the main outcrop area of the formation. Small exposures in the northern portion of the map exceed 300 feet.

Tbm — **Bryn Mawr Formation (Tertiary, Oligocene?) -** White, yellow, and brown gravel and sand with local silt and clay, commonly cemented with iron oxide. Clasts are composed of quartz and quartzite and are not more than 5 inches long. The Bryn Mawr occurs in isolated upland terrace remnants between 200 and 400 feet altitude. It is no more than about 30 feet thick.

Kp — **Potomac Formation[1] (Upper Cretaceous) -** Variegated, thick-bedded clay, sandy clay, sand, and gravelly sand. Local gravel beds, especially near the base. Sand beds are cross bedded and planar bedded and comprise mostly quartz, with lesser feldspar and mica. Gravel consists mainly of quartz and quartzite. The clay beds are lenticular and kaolinitic, and siderite pellets are locally abundant. Thickness ranges from 0 to 150 feet thick, but appears to be no more than 20 feet thick in the map area. The Potomac Formation is exposed in small areas in the northern part of the map at altitudes of about 300 feet.

[1] The Potomac Formation was suggested for use in Pennsylvania by Owens (1999) as a substitute for the Patapsco and Raritan Formations in Pennsylvania.

Jd — **Diabase -** Dark-gray to black, fine- to coarse-grained diabase dikes composed largely of plagioclase and augite. Surrounding rocks may be thermally altered.

Trs — **Stockton Formation (Upper Triassic) -** Light- to medium-gray and light-yellowish-gray, thin- to thick-bedded, fine- to coarse-grained, feldspathic sandstone, arkose and arkosic conglomerate with pebbles of quartz, quartzite and metamorphic rocks; grayish-red to moderate-reddish-brown, and light- to medium-gray siltstone and shale; and grayish-red to reddish-brown , thin- to thick-bedded, very fine to medium-grained, arkosic sandstone, generally fining upward with abrupt lateral lithic changes.

Op — **Pegmatite -** Coarse-grained quartz, feldspar, and mica in veins

Osg — **Swarthmore Granodiorite (Ordovician)**--Medium- to coarse-grained, generally massive, microcline-oligoclase-quartz-biotite-muscovite gneiss with accessory epidote, sphene, and apatite, and associated migmatite, granulite, and amphibolite. The contact between the Wissahickon Formation (CZw) and the Swarthmore is characterized by a series of replacement textures. However, a thrust fault brings the Wissahickon south over the granodiorite, further complicating the relations between these units

OCc — **Conestoga Limestone (Lower Ordovician to Middle Cambrian)--**Very light- to medium-gray, fine- to coarse-grained, thin-bedded, medium- bedded at base, impure (highly micaceous) limestone and minor shale; phyllitic in places with argillaceous partings parallel to regional cleavage; local dark-gray, fine-grained, thin-bedded dolomite in lower part. Lower contact probably unconformable. Maximum thickness of about 750 feet.

Ce — **Elbrook Formation (Upper and Middle Cambrian)--**Light-gray, laminated to thin-bedded, siliceous, fine-grained, phyllitic limestone and lesser dolomite which weathers to a shaly, light-yellowish- brown carbonate rock. Interbedded with cream-colored to pure-white, fine-grained, thin-bedded, laminated dolomitic marble. Concentrations of mica are left as a pressure-solution residue parallel to regional cleavage. The lower contact is gradational. The thickness is approximately 800 feet.

Cl — **Ledger Dolomite (Middle Cambrian)--**Light- to medium-gray, thin-bedded to massive, coarse-grained, high- magnesium dolomite with some siliceous beds which weather to rust-stained, granular, cherty layers and interbedded laminated limestone that weathers to a rough granular surface. The lower part of the unit is characterized by alternating light and dark layers and porous, cherty layers. Weathers to a characteristic light-yellow, earthy soil. Lower contact is gradational. Thickness is approximately 1,000 feet.

Cc — **Chickies Quartzite (Lower Cambrian)--**Upper part consists of gray, medium-grained, laminated to medium-bedded and massive, cross bedded, vitreous quartzite and fine-grained, thin-bedded, feldspathic quartzose schist, conglomeratic at base. Lower part consists of gray, coarse-grained, tourmaline-bearing quartzite, arkosic-pebble conglomerate, and black slate and biotite schist, Lower contact unconformable. Thickness about 1,000 feet

Cza — **Amphibolite (Cambrian and Late Proterozoic)--**Fine- to coarse-grained, "salt and pepper"-textured, hornblende-plagioclase-epidote- bearing amphibolite, epidote amphibolite, and well-foliated metagabbro, with minor magnetite in discontinuous layers, lenses and pods.

Czs — **Serpentinite (Cambrian and Late Proterozoic)--**Serpentinite and related ultramafic rocks in highly sheared tectonic lenses, pods, and slivers with abundant actinolite and chlorite. Forms a thin poor soil.

Czw — **WISSAHICKON FORMATION (Cambrian and Late Proterozoic)--**Medium- to dark-gray to black, brownish-gray to slightly rusty weathering, medium- to coarse-grained, aluminous, quartz-feldspar-biotite-muscovite schist, garnetiferous in places, feldspathic metagraywacke with thin interbedded amphibolites, and lenses and pods of altered ultramafic rocks. Thickness is difficult to determine because of folding, but possibly as much as 2000 feet thick. Contact with the Swarthmore Granodiorite (Osg) is probably a back-thrust fault bringing the Wissahickon south over the granodiorite. The upper surface of the Wissahickon in commonly chemically weathered to saprolite, consisting of soft decomposed clayey, silty, and sandy material that preserves the original structure of the parent rock. It may reach more than 50 feet in thickness (Fergusson, 1988).

Ya — **Amphibolite (Middle Proterozoic)--**Medium- to coarse-grained, very dark gray to black, hornblende-plagioclase schist and gneiss with accessory hypersthene, magnetite, epidote, zircon, pyrite and sphene. Probable protoliths are sedimentary, generally associated with calcareous schists and gneisses, and igneous, associated with both metaplutonic and metavolcanic rocks

Ymg — **Amphibolitic migmatite and related hybrid rocks--**Interlayered quartz-orthoclase-biotite-hornblende gneiss, with accessory epidote, titanite, staurolite, and augite, garnetiferous in places, and amphibolite. In places grades into a gray gneiss of intermediate composition.

EXPLANTION OF MAP SYMBOLS

Fault
Contact

GEOLOGIC MAP OF THE FRANKFORD AND GERMANTOWN QUADRANGLES, PHILADELPHIA AND MONTGOMERY COUNTIES, PENNSYLVANIA AND BURLINGTON COUNTY, NEW JERSEY

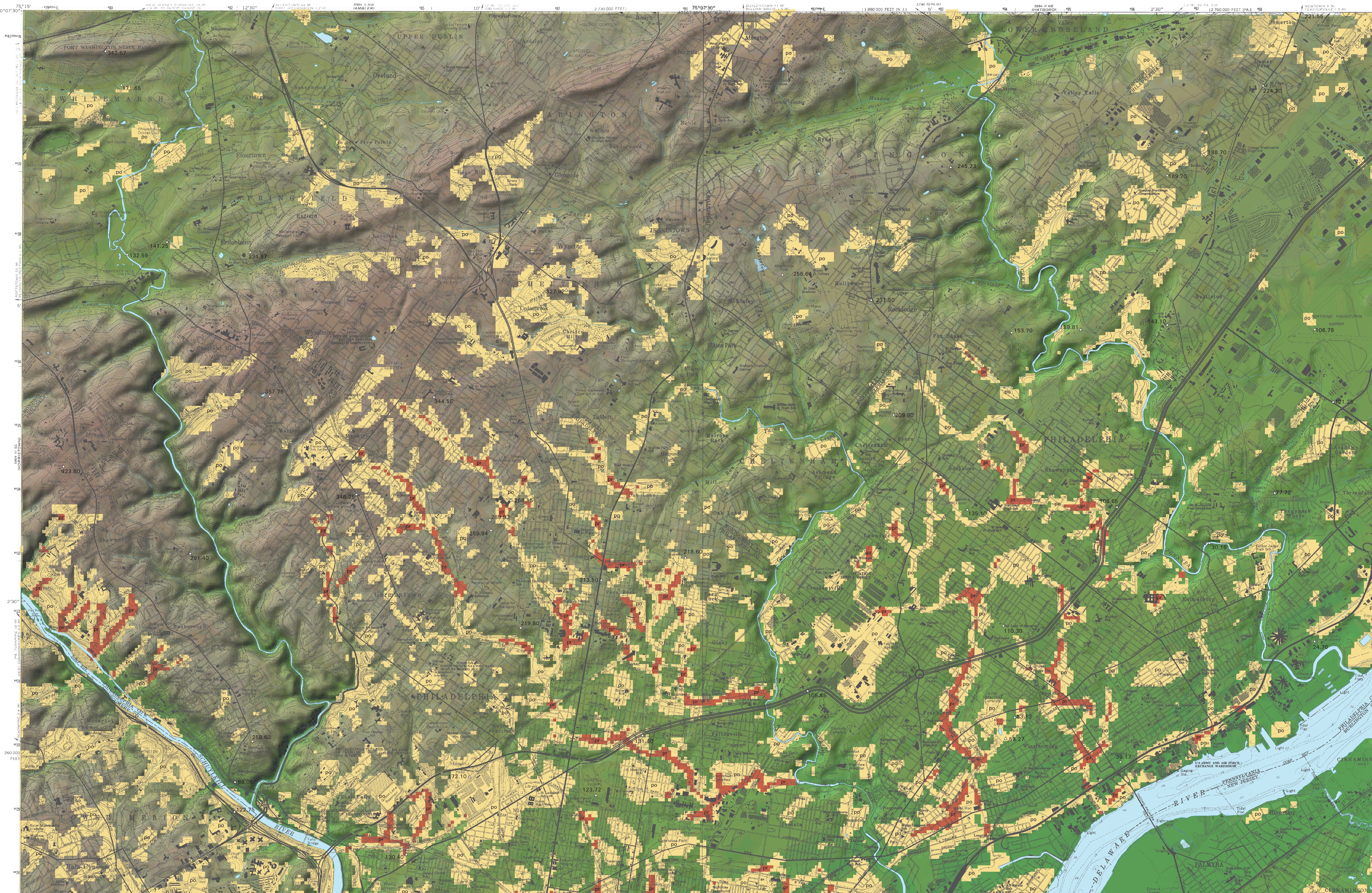
By
Jack B. Epstein and Peter G. Chirico

2000

U. S. DEPARTMENT OF THE INTERIOR
U. S. GEOLOGICAL SURVEY

Prepared in Cooperation with the
U. S. ARMY CORPS OF ENGINEERS

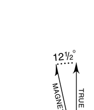
OPEN-FILE REPORT 00-224
PLATE 2



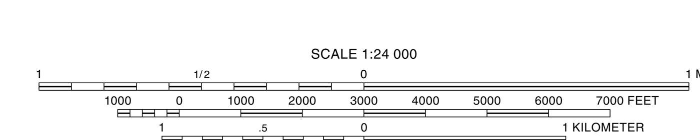
Base from U.S. Geological Survey Digtial Raster Graphics (DRG's) of Frankford, 1997 and Germantown,1997.

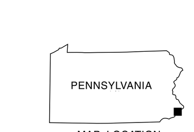
North American Datum of 1927 (NAD 27)
Projection: Universal Transverse Mercator (UTM), zone 18

GPS control by U.S. Geological Survey and City of Philadelphia. U.S. Geological Survey GPS control by J.L. Blair, K.Lagueux and P.G. Chirico, March 2000

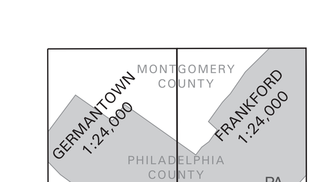


APPROXIMATE MEAN DECLINATION, 1998





MAP LOCATION



Study area quadrangle index map

MAP NOTE

It is important to note that the exact location of the fill, its total thickness or depth, its engineering characteristics, and nature of ground-water movement need to be ascertained to judge the potential for subsidence or settling of the ground. Zones designated as possible or probable fill do not imply the occurrence of, nor the potential for, structural subsidence. The map does not show the depth of possible or probable fill, the origin or composition of the fill material or any engineering characteristics of sites located in or near fill areas.

MAP SHOWING DISTRIBUTION OF FILL IN THE FRANKFORD AND GERMANTOWN QUADRANGLES, PHILADELPHIA AND MONTGOMERY COUNTIES, PENNSYLVANIA AND BURLINGTON COUNTY, NEW JERSEY

By
Peter G. Chirico and Jack B. Epstein

2000

DESCRIPTION OF MAP UNITS

po — **Possible Fill -** GIS grid analysis results showing positive topographic change (5 or more feet of fill from between 1899 and 1997) *or* evidence of a buried stream channel.

pr — **Probable Fill -** GIS grid analysis results showing positive topographic change (5 or more feet of fill from between 1899 and 1997) *and* evidence of a buried stream channel.

DESCRIPTION OF MAP SYMBOLS

△ 268.15 — **GPS Ground Elevation -** Global Positioning System (GPS) ground control elevation points collected by the U. S. Geological Survey and the City of Philadelphia. These elevations form the control network used to evaluate digital elevation model (DEM) interpolation and subsequent grid analysis.

Elevation values are in feet above mean sea level