9 Geodetic and Control Surveys Problems

NORTH AMERICAN DATUMS

1. Which of the following statements correctly describes the origin of the North American Datum of 1927 (NAD27)?

(A) The origin of NAD27 is at Meades Ranch in Kansas.

(B) The origin of NAD27 is geocentric.

(C) The geoidal height of the origin of NAD27 is assumed to be zero.

(D) Both A and C are true.

2. Which of the following statements correctly describes the North American Datum of 1983 (NAD83)?

(A) The origin of NAD83 is intended to be geocentric.

(B) NAD83 is the horizontal control datum used throughout the western hemisphere.

(C) Coordinates based on NAD83 have replaced those based on NAD27 throughout the U.S.

(D) Both A and B are true.

3. NAD83 uses a figure to represent the earth that closely approximates its shape, but may be described mathematically by a few definite parameters. The shape is a

(A) biaxial ellipsoid rotated about its minor axis

(B) mean earth ellipsoid

(C) biaxial ellipsoid rotated about its major axis

(D) triaxial ellipsoid

4. Which of the following statements correctly characterizes the transformation of coordinates from NAD27 to NAD83?

(A) There is not one simple, consistent method to reliably transform coordinates from NAD27 to NAD83.

(B) The transformation of ellipsoidal coordinates in terms of $\Delta\phi$, $\Delta\lambda$, and Δh from NAD27 to NAD83 can be accurately accomplished with a simple, one-step mathematical formula, but the transformation of Cartesian coordinates cannot.

(C) The transformation of Cartesian coordinates in terms of Δx, Δy, and Δz from NAD27 to NAD83 can be accurately accomplished with a simple, one-step mathematical formula, but transformation of ellipsoidal coordinates cannot.

(D) The transformation of state plane coordinates expressed in NAD27 to NAD83 involves only a change in the origin of the coordinates.

5. Flattening and the length of the semimajor axis are two parameters often used to define the reference ellipsoids associated with geodetic datums. What are the dimensions used to define the reference ellipsoids associated with NAD27 and NAD83?

	datum	reference ellipsoid	semimajor	flattening
(A)	NAD83	GRS 80	6,378,137.0 m	$\frac{1}{298.257222101}$
	NAD27	Clarke 1866	6,378,206.4 m	$\frac{1}{294.9786982}$
(B)	NAD83	Fischer 1960	6,378,166.0 m	$\frac{1}{298.36714202}$
	NAD27	Clarke 1858	6,378,361.4 m	$\frac{1}{294.26982312}$
(C)	NAD83	WGS 84	6,378,137.0 m	$\frac{1}{298.257223563}$
	NAD27	Clarke 1866	6,378,206.4 m	$\frac{1}{294.9786982}$
(D)	NAD83	WGS 72	6,378,135.0 m	$\frac{1}{298.2623209}$
	NAD27	Clarke 1858	6,378,206.4 m	$\frac{1}{294.9786982}$

6. What is the geoid?

(A) a surface defined by the earth's gravity

(B) a surface that is flattened without tearing or stretching

(C) a surface that would closely resemble the oceans' surfaces if they were completely still

(D) Both A and C are true.

7. How is the flattening, f, of a reference ellipsoid defined in terms of the semimajor axis, a, and the semiminor axis, b?

(A) $f = \frac{b - a}{b}$

(B) $f = \frac{a - b}{a}$

(C) $f = b - a$

(D) $f = \frac{a + b}{b}$

8. What is the cause of geoidal undulation?

(A) The presence of magnetically attractive ores within the earth cause the geoid to undulate.

(B) The center of mass of the earth does not coincide with the center of the geoid.

(C) The ellipsoid is not coincident with the geoid.

(D) The mass of the earth is irregularly distributed and, therefore, the geoid is also irregular.

9. What is a common vertical datum used in the U.S.?

(A) the U.S. Standard Datum

(B) the IGL Datum

(C) the NAP Datum

(D) the National Geodetic Vertical Datum of 1929

10. In considering surveys of a very large extent, can a level surface at mean sea level be considered parallel with a level surface 100.0 m above mean sea level?

(A) No, a level surface is perpendicular everywhere to the direction of gravity.

(B) Yes, every level surface is parallel to every other level surface.

(C) No, level surfaces that are 100.0 m apart at the equator would be approximately 99.5 m apart at the poles, so they cannot be considered parallel.

(D) Both A and C are true.

11. Until the 1940s, the U.S. Coast and Geodetic Survey typically stamped elevations on the monuments they set. In one sense, those elevations would now be obsolete because they are

(A) in feet, not meters

(B) based on the Clarke reference ellipsoid

(C) not in the North American Datum of 1988

(D) dynamic rather than orthometric

12. Proceeding northward from the equator, which of the following will NOT occur?

(A) The acceleration of gravity increases.

(B) Meridians converge.

(C) Latitudinal lines are parallel.

(D) The distance along the earth's surface represented by a degree of latitude remains constant.

13. If the numbers to the right of the decimal are significant, which of the following is the nearest to the actual precision of the following coordinate?

$$\phi = 39°30'15.3278''\ \text{N}$$
$$\lambda = 109°54'11.1457''\ \text{W}$$

(A) ± 0.01 ft

(B) ± 0.10 ft

(C) ± 1.0 ft

(D) ± 10.0 ft

14. Which statement about biaxial and triaxial ellipsoids is correct?

(A) The reference ellipsoid for NAD83 is triaxial and the reference ellipsoid for NAD27 is biaxial.

(B) The length of the semimajor axis is constant in both a biaxial ellipsoid and a triaxial ellipsoid.

(C) The equator of a triaxial ellipsoid is elliptical; the equator of a biaxial ellipsoid is a circle.

(D) Both triaxial and biaxial ellipsoids have flattening at the equator.

15. What constitutes the *realization* of a geodetic datum?

(A) the assignment of a semimajor axis and another parameter, such as the first eccentricity, flattening, and/or semiminor axis

(B) the monumentation of the physical network of reference points on the earth's surface that is provided with known coordinates in the subject datum

(C) an initial point at a known latitude and longitude, and a geodetic azimuth from there to another known position, along with two parameters of the associated ellipsoid, such as its semimajor and semiminor axes

(D) the transformation of its coordinates into another datum using the seven parameters of the Bursa-Wolfe process

16. Which of the following statements about reference ellipsoids is NOT correct?

(A) The semimajor axis and flattening can be used to completely define an ellipsoid.

(B) The Clarke 1866 spheroid is the reference ellipsoid of the North American Datum of 1927 (NAD27), but it is not the datum itself.

(C) NAVD is the reference ellipsoid of the North American Datum of 1983 (NAD83).

(D) Six elements are required if a particular reference ellipsoid is to be used in a geodetic datum.

17. Which of these was NOT intended to be a geocentric datum?

(A) NAD27

(B) Australian Geodetic Datum 1966

(C) South American Datum 1969

(D) all of the above

18. Which of the following are aspects of a good High Accuracy Reference Networks (HARNs) station?

(A) inclusion in an NGS sanctioned readjustment

(B) vehicle accessibility

(C) good overhead visibility

(D) all of the above

19. Which of the following statements about the geoid is NOT true?

(A) The mean sea level (MSL) and the geoid are not equivalent.

(B) It does not precisely correspond to the topography of the earth's dry land.

(C) It is bumpy with peaks and valleys.

(D) It never departs from true ellipsoidal form.

MAP PROJECTIONS

20. Which of the following best defines map projection?

(A) the systematic transformation of state plane coordinates into Cartesian coordinates

(B) the rigorous mathematical transference of points on a spheroid to the points on a plane surface

(C) the function of relating an ellipsoid of revolution to the geoid

(D) the mathematical development of the graticule representing the geographical lines on a globe

21. Which of the following map projections is used as the basis of state plane coordinate systems in the U.S.?

(A) the Lambert projection

(B) the oblique transverse Mercator projection

(C) the transverse Mercator projection

(D) all of the above

22. A developable surface is best described as a

(A) portion of the earth's surface that corresponds to mean sea level

(B) polar gnomonic map projection

(C) plane figure upon which the information from a spheroid may be projected and then flattened without gross distortion or tearing

(D) surface that a map of a portion of the earth's surface may be drawn upon without any distortion

23. What characteristic of a map projection preserves the shape of small figures from the ellipsoid to the map?

(A) propagation

(B) standardization

(C) spatiality

(D) conformality

24. A rhumb line, not a cardinal line, has been drawn between two points on a map produced from a Mercator projection. Does the line represent the shortest distance between those two points on the earth?

(A) No, while the rhumb line would appear straight on a Mercator projection, it would not follow the arc of a great circle.

(B) Yes, the described loxodrome would follow the shortest path between two points on a conformal projection.

(C) No, the rhumb line would follow the arc of a great circle on the Mercator projection and therefore would have a constant geodetic direction.

(D) Yes, the rhumb line would follow the arc of a great circle on the Mercator projection.

25. Which of the following curves appears as a straight line on a gnomonic map projection?

(A) the parallels of latitude

(B) rhumb lines

(C) the arcs of great circles

(D) the arcs of small circles

26. In the State Plane Coordinate System 1983, also know as SPCS83, the convergence is symbolized by which of the following?

(A) phi, ϕ
(B) omega, ω
(C) mu, μ
(D) gamma, γ

27. Which of the following statements does NOT properly describe a difference between SPCS27, the State Plane Coordinate System based on NAD27, and SPCS83, the State Plane Coordinate System based on NAD83?

(A) There have been some changes in the distances between the SPCS zones and their origins.
(B) SPCS83 coordinates are expressed in more units than were SPCS27 coordinates.
(C) There are fewer SPCS83 zones than there were SPCS27 zones in some states.
(D) For the first time, the scale factor limit of 1 part in 10,000 changed in SPCS83.

THE LAMBERT PROJECTION

28. Which of the following terms may be correctly applied to the Lambert map projection that is used as the foundation for state plane coordinates in the U.S.?

(A) conformal and conic
(B) azimuthal and equal-area
(C) cylindrical and conformal
(D) conic and sinusoidal

29. The Lambert projection employs the Greek letter θ as the symbol for what important quantity?

(A) scale factor
(B) standard parallel
(C) central meridian
(D) mapping angle

30. The mapping plane used in the Lambert projection is often called a *secant cone*. Which of the following characteristics describes such a developable surface?

(A) The central axis of the cone is imagined to be a projection of the polar axis of the earth.
(B) The bottom of the cone is imagined to terminate at the earth's equator.
(C) The relationship between the altitude of the cone and its radius is always 1.55.
(D) The cone is imagined to intersect the ellipsoid along two standard parallels.

31. In a Lambert projection, the scale factor varies with which of the following quantities?

(A) longitude
(B) elevation
(C) latitude
(D) mapping angle

32. The Lambert projections used as the basis of state plane coordinates in the U.S. employ two lines of strength, or standard parallels. The scale along a standard parallel in such a projection is

(A) the smallest in the zone of a Lambert projection
(B) variable in the Lambert projection
(C) the largest in the zone of a Lambert projection
(D) 1 in a Lambert projection

33. Meridians of longitude and parallels of latitude are represented differently in the Lambert projection. Which of the following statements best describes the difference between these two categories of lines?

(A) Meridians of longitude are represented by straight lines converging at the pole; parallels of latitude are represented by the arcs of concentric circles.
(B) Meridians of longitude are represented by the arcs of concentric circles; parallels of latitude are represented by straight lines.
(C) Parallels of latitude are represented by complex curves; meridians of longitude are represented by unequally spaced straight lines.
(D) Parallels of latitude are represented by curves concave toward the pole; meridians of longitude are represented by complex curves concave toward the central meridian.

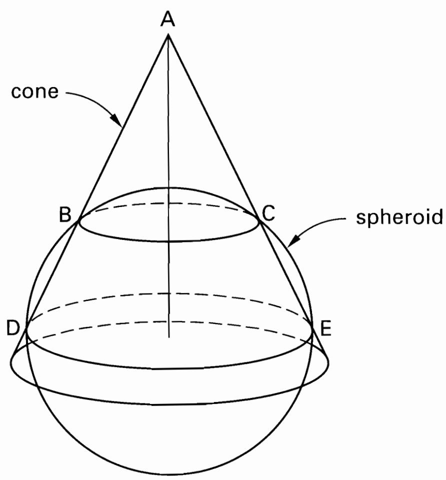
34. How many states use the Lambert conformal projection exclusively as the basis of their state plane coordinate systems?

(A) 18
(B) 20
(C) 29
(D) 33

35. State plane coordinate systems based on Lambert conformal projections have been designed to minimize the distortion of grid lengths with respect to geodetic lengths. Where coverage by a single grid with a latitudinal extent of 158 statute miles is possible, which ratio most nearly represents the maximum difference between the grid and geodetic lengths of a line?

(A) 1:5000
(B) 1:10,000
(C) 1:40,000
(D) 1:80,000

36. The following two problems refer to the illustration shown.



36.1. Only part of the cone represented in the illustration is actually used in the developed Lambert projection. What is the typical portion included in a zone?

(A) Three-fifths of the zone is made up of the area of the cone within the spheroid—that is, between the standard parallels. One-fifth of the zone is the area north of the northerly standard parallel, and one-fifth is south of the southerly standard parallel.

(B) Only the portion of the cone within the spheroid is included in the zone.

(C) All of the area of the cone outside of the standard parallels BC and DE is included in the zone.

(D) Four-sixths of the zone is made up of the area of the cone within the spheroid—that is, between the standard parallels. One-sixth of the zone is the area north of the northerly standard parallel (BC) and one-sixth is south of the southerly standard parallel (DE).

36.2. What is the usual alignment of the axis of the cone in the illustration?

(A) perpendicular to the plane of the ecliptic

(B) coincident with an extension of the earth's axis of rotation

(C) arbitrary and has no typical arrangement

(D) coincident with an extension of the earth's magnetic pole

THE TRANSVERSE MERCATOR PROJECTION

37. Two mapping projections have been used in the development of nearly all of the state plane coordinate systems in the U.S.; one is the Lambert projection and the other is the transverse Mercator projection. What is the significance of the word *transverse* in the name of the transverse Mercator projection?

(A) It refers to the characteristic representation of a line of constant azimuth on the spheroid as a straight line.

(B) It is used to indicate that the axis of the cylinder employed in the projection is perpendicular to the axis of the spheroid.

(C) It is used because the only straight line on the projection is the central meridian.

(D) The cylindrical surface used in the transverse Mercator projection is tangent to the spheroid at the equator.

38. Which of the following statements describes the treatment of scale in the Lambert and the transverse Mercator projections?

(A) The Lambert projection scale is variable with respect to changes in longitude; in the transverse Mercator projection, it varies with respect to latitude.

(B) In the transverse Mercator projection, the lines of exact scale are meridians of longitude; in the Lambert projection, they are called *standard parallels of latitude.*

(C) The transverse Mercator projections used as the foundation of state plane coordinate systems are designed to limit scale distortion to 1 part in 20,000; in Lambert-based systems, distortion is limited to 1 part in 10,000.

(D) The scale is constant up and down the central meridian of a transverse Mercator projection; it is variable along the central meridian of a Lambert projection.

39. The grid imposed on a transverse Mercator projection indicating a particular state plane coordinate system is composed of straight lines. However, the geographical lines—that is, the parallels of latitude and meridians of longitude—are not straight. What symbol is used to indicate the angle between grid north through a particular point and the meridian of longitude through the same point?

(A) ϕ

(B) θ

(C) $\Delta\alpha$

(D) λ

40. The cylinder is the developable surface employed in the transverse Mercator projection. Which of the following statements correctly describes the configuration of the cylinder used in the state plane coordinate systems based on the transverse Mercator projection?

(A) The axis of the cylinder is imagined to be perpendicular to the rotational axis of the spheroid; it intersects the spheroid along two meridians of longitude.

(B) The axis of the cylinder is imagined to be perpendicular to the rotational axis of the spheroid; it intersects the spheroid along two ellipses that are equally distant and parallel with the plane of the central meridian.

(C) The axis of the cylinder is imagined to be perpendicular to the rotational axis of the spheroid; it is tangent to the spheroid along the central meridian.

(D) The axis of the cylinder is imagined to be perpendicular to the rotational axis of the spheroid; it is tangent to the spheroid along the equator.

41. Which of the following statements correctly describes some of the features of the projection known as the Universal Transverse Mercator (UTM)?

(A) UTM employs 60 zones; each includes 6° of longitude.

(B) The foundation of UTM is the Jacobi reference ellipsoid; the coordinates in each zone are expressed in meters.

(C) The foundation of UTM includes five different reference ellipsoids; the system is used to map from 84°Nϕ to 80°Sϕ.

(D) Both A and C are true.

42. Which of the following does NOT correctly state a difference between the Transverse Mercator coordinate system used in SPCS and the Universal Transverse Mercator (UTM) coordinate system?

(A) The UTM system of coordinates was designed and established by the United States Army in cooperation with NATO member nations. The Transverse Mercator SPCS was established by the United States Coast and Geodetic Survey.

(B) The official unit of measurement in the UTM system of coordinates is the meter. The official unit in Transverse Mercator SPCS83 is always the international foot.

(C) The UTM system of coordinates is augmented by the Universal Polar Stereographic (UPS) to complete its worldwide coverage. The Transverse Mercator SPCS does not have such a broad scope.

(D) The scale factor in the UTM system of coordinates can reach 1 part in 2500. In the Transverse Mercator SPCS, the scale factor is usually no more than 1 part in 10,000.

43. Which of the following heights is NOT measured along a line perpendicular to the ellipsoid?

(A) ellipsoidal height

(B) geoid height

(C) geodetic height

(D) orthometric height

44. Which of the following parameters is NOT usually paired with the semimajor axis to define a reference ellipsoid?

(A) semiminor axes

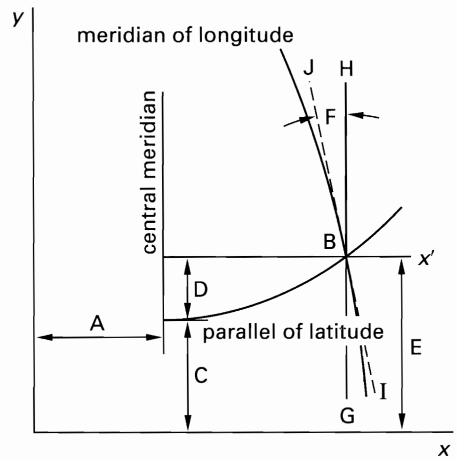
(B) reciprocal of the flattening

(C) eccentricity

(D) reciprocal of the eccentricity

STATE PLANE COORDINATE SYSTEMS

45. The following six problems refer to the illustration shown.



The illustration shows the geometrical relationship between some of the significant lines comprising a state plane coordinate grid based on a transverse Mercator projection.

45.1. Considering NAD27 state plane coordinate positions derived from a transverse Mercator projection, the arbitrary constant represented by the letter A is most nearly

(A) 150,000 m
(B) 300,000 ft
(C) 500,000 ft
(D) 700,000 ft

45.2. Considering NAD83 state plane coordinate positions derived from a transverse Mercator projection, what arbitrary constant, represented by the letter A, will be used?

(A) 100,000 m, 300,000 m, and 900,000 m
(B) 200,000 m, 400,000 m, 600,000 m, and 800,000 m
(C) 213,000 m, 850,000 m, and 165,000 m
(D) all of the above and more

45.3. Line GH is parallel with the central meridian, the dashed line IJ is not parallel, and the angle between them is symbolized by $\Delta\alpha$. Which of the following statements would be correct for an observer standing at station B and facing geodetic north?

(A) The observer would find line IJ on the left of geodetic north and line GH on the right.
(B) The observer would find line GH on the left of geodetic north and line IJ on the right.
(C) The observer would find both line GH and line IJ on the left of geodetic north.
(D) The observer would be looking along line IJ and line GH would be on the right.

45.4. Which of the following labels are commonly used for the distances labeled C, D, and E?

(A) $C = y_o$
$D = \Delta\phi$
$E = y$-coordinate
(B) $C = \pm ab$
$D = \Delta\phi$
$E = \Delta\lambda$
(C) $C = H$
$D = V$
$E = y_o$
(D) $C = y$-coordinate
$D = y_o$
$E = \Delta\phi$

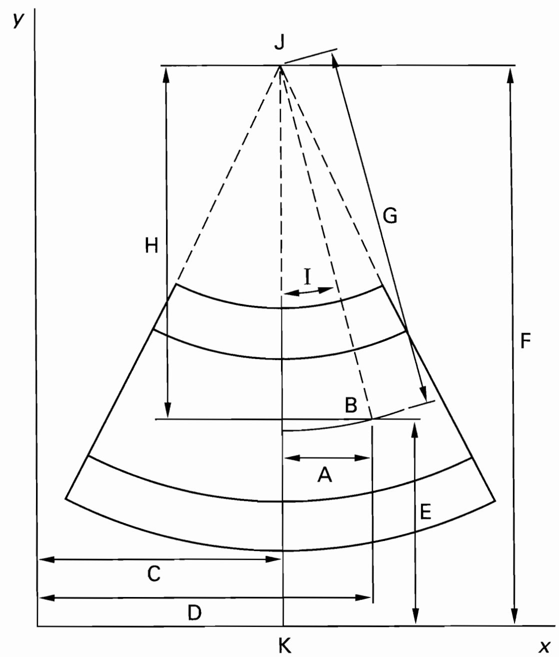
45.5. Which of the distances is known as a *spheroidal perpendicular* and is equal to the expression $H\Delta\lambda'' \pm ab$?

(A) A
(B) x'
(C) C
(D) D

45.6. Which of the following expressions is correct for the angular value symbolized by the letter F?

(A) $\pm\Delta\alpha$
(B) $\Delta\alpha'$
(C) $+\Delta\alpha$
(D) $-\Delta\alpha$

46. The following six problems refer to the illustration shown.



The illustration shows the geometrical relationship between some of the significant lines comprising a state plane coordinate grid based upon a Lambert projection.

46.1. Considering NAD27 state plane coordinate positions derived from a Lambert projection, what is the arbitrary constant represented by the letter C?

(A) 100,000 ft
(B) 500,000 ft
(C) 1,000,000 m
(D) 2,000,000 ft

46.2. Which of the following symbols most completely describes the angular value labeled I?

(A) $-\theta$
(B) $+\theta$
(C) θ
(D) θ'

46.3. Which of the following expressions is commonly used to represent the distance labeled A?

(A) x'
(B) $R\cos\theta$
(C) R_b
(D) both A and B

46.4. Using the most typical symbols, which of the formulas given is equivalent to F − E = H?

(A) $R - x = y$
(B) $R\cos\theta - y = R_b$
(C) $P - R\sin\theta = C$
(D) $R_b - y = R\cos\theta$

46.5. What is the name usually given to the line labeled JK in the illustration?

(A) the y-axis
(B) ϕ_o
(C) the central meridian
(D) λ_1

46.6. The distance labeled D represents the x-coordinate of station B, and the distance labeled E is its y-coordinate. Which of the following formulas correctly represents these coordinates?

(A) $x = 2{,}000{,}000 - x'$
$y = R_b - R\cos\theta$
(B) $x = R\sin\phi + C$
$y = R_b - R\cos\theta$
(C) $x = 2{,}000{,}000 + x'$
$y = R\cos\theta - R_b$
(D) $x = R\sin\theta + C$
$y = R_b - R\cos\theta$

47. Some elements are constant for each zone of state plane coordinates based on a Lambert projection, and some vary with each station. Which elements are constant?

(A) Each zone has a unique origin, a constant R_b, and a distance of 2,000,000 ft from the y-axis to the central meridian.
(B) Each zone has a unique central meridian, a constant x', and a distance of 2,000,000 ft from the y-axis to the central meridian.
(C) Each zone has a unique central meridian, a constant R, and a distance of 2,000,000 ft from the x-axis to the central meridian.
(D) Each zone has a unique central meridian, a constant R_b, and a distance of 2,000,000 ft from the x-axis to the central meridian.

48. The following lists are made up of variables from state plane coordinate systems based on the Lambert projection and the transverse Mercator projection. Which lists show only those variables that vary with latitude?

(A) Lambert: $\Delta\alpha$, H, V, and a
transverse Mercator: θ, R, scale factor, and b
(B) Lambert: ℓ, x', and θ
transverse Mercator: b, c, and y_o
(C) Lambert: R, scale factor, and θ
transverse Mercator: y_o, H, V, and a
(D) Lambert: y_o, H, V, and a
transverse Mercator: R, scale factor, and θ

49. Most state plane coordinate systems are designed to limit scale distortion to 1 part in 10,000. If this goal has been achieved, within what limits should the scale factor fall?

(A) not less than 0.9994563;
not more than 1.0051020
(B) not less than 0.9999000;
not more than 1.0001000
(C) not less than 0.9999569;
not more than 1.0000839
(D) not less than 0.9999823;
not more than 1.0001787

50. Between the standard parallels of a state plane coordinate zone based on the Lambert projection, the scale factor remains within what specific limits?

(A) The scale factor is always greater than 1 between the standard parallels.
(B) The scale factor is always greater than 1 and less than 2 between the standard parallels.
(C) The scale factor is always greater than zero and less than 1 between the standard parallels.
(D) The scale factor is always less than zero between the standard parallels.

51. In state plane coordinate systems derived from a transverse Mercator projection, what value is the scale factor based on?

(A) $\Delta\lambda''$
(B) $\Delta\phi$
(C) y-coordinate
(D) x'

52. Considering a state plane zone based on the transverse Mercator projection, the scale factor outside the lines of exact scale is always

(A) greater than 1 outside the lines of exact scale
(B) 1 outside the lines of exact scale
(C) less than zero outside the lines of exact scale
(D) greater than zero and less than 1 outside the lines of exact scale

53. Which factor is used to directly reduce distances measured on the topographic surface of the earth to the state plane?

(A) the scale factor
(B) the K-factor
(C) the sea-level factor
(D) the combination factor

54. What approximation of the radius of the reference ellipsoid has traditionally been used as the basis for calculating the sea-level factor?

(A) 6,378,000 m
(B) 20,906,000 ft
(C) 20,925,000 ft
(D) 24,000,000 ft

55. It is sometimes appropriate to apply a weighted mean scale factor to a line of 5 mi or more. Which of the following circumstances would warrant such a refinement?

(A) a long, predominantly east-west line on the Lambert projection or a long, predominantly north-south line on the transverse Mercator projection
(B) a long, predominantly east-west line on the transverse Mercator projection or a long, predominantly north-south line on the Lambert projection
(C) a long line near the center of the zone on the transverse Mercator projection and a similar line on the Lambert projection
(D) a long line near the edge of the zone on the transverse Mercator projection and a similar line on the Lambert projection

56. There is a parallel of latitude known as ϕ_o in each zone based on the Lambert projection. Which of the following statements correctly identifies some of the special characteristics of this parallel of latitude?

(A) All of the geodetic lines in the zone are slightly concave toward this parallel of latitude.
(B) The scale factor ratio is lowest along this parallel of latitude.
(C) The latitude of this line is equidistant from each of the standard parallels.
(D) Both A and B are true.

57. Which of the following symbols is normally used to indicate the second-term correction applied to the direction of long lines in the Lambert state plane coordinate system?

(A) ω
(B) θ'
(C) $\Delta\alpha'$
(D) σ

58. What is the formula used to convert a geodetic azimuth to a grid azimuth in the Lambert conformal projection when a relatively short line is involved?

(A) grid azimuth = geodetic azimuth + θ
(B) grid azimuth = geodetic azimuth − θ
(C) grid azimuth = θ − geodetic azimuth
(D) grid azimuth = geodetic azimuth + $\theta - \theta'$

59. Which of the following expressions is equal to the mapping angle in the transverse Mercator projection?

(A) $x' + 500{,}000$
(B) $y_o + V\left(\frac{\Delta\lambda''}{100}\right)^2 \pm c$
(C) $H\Delta\lambda'' \pm ab$
(D) $\Delta\lambda'' \sin\phi + g$

60. What is the relationship between the mapping angle, θ, and the distance from the central meridian for a station in a zone of a state plane coordinate system based upon the Lambert projection?

(A) The absolute value of θ is always larger than the difference in longitude from the central meridian.

(B) θ is not always the same for a specific meridian of longitude.

(C) The absolute value of θ is always the same as the difference in longitude from the central meridian.

(D) The absolute value of θ is always smaller than the difference in longitude from the central meridian.

61. Which of the following expressions is equal to the mapping angle, θ, in a state plane coordinate system based on the Lambert projection?

(A) $\Delta\lambda\ell$

(B) $\tan^{-1}\left(\dfrac{x'}{R_b - y}\right)$

(C) $\sin^{-1}\left(\dfrac{R_b - y}{R}\right)$

(D) both A and B

SHORT GEODETIC CALCULATIONS

62. The geodetic azimuth (from south) from station Telo to station Klamath is 186°15′22.″21, and the mapping angle at station Telo is +00°40′21.″85. What is the grid azimuth from station Telo to station Klamath if the second term is not considered?

(A) 05°35′00.″36

(B) 06°55′44.″06

(C) 185°35′00.″36

(D) 186°55′44.″06

63. The grid azimuth from station Exeter to station Abott is 212°32′14.″1, and the mapping angle at station Exeter is +00°27′45.″2. What is the geodetic azimuth from station Abott to station Exeter if the second term is not considered?

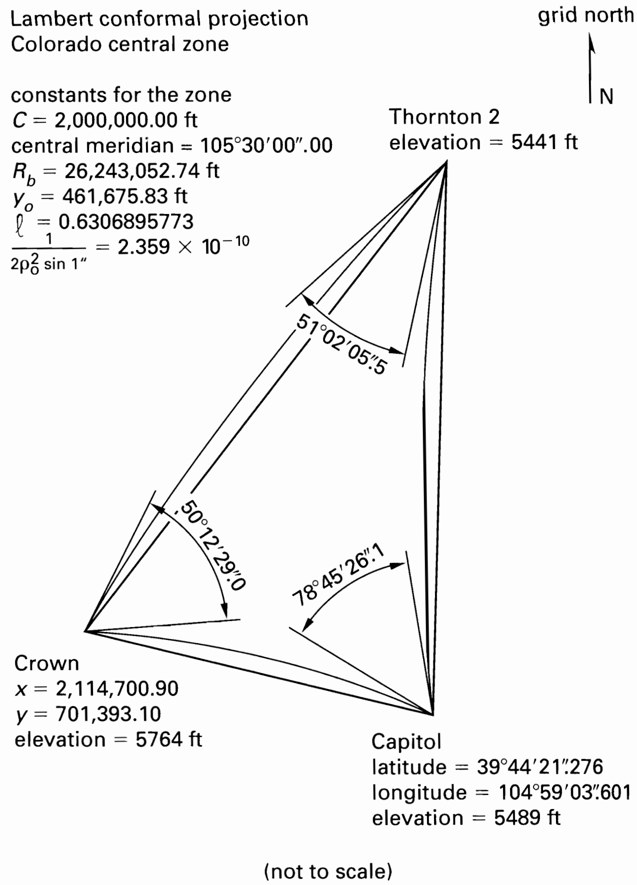
(A) 32°59′59.″3

(B) 212°04′28.″9

(C) 212°59′59.″3

(D) insufficient information given

64. The following seven problems refer to the illustration shown.



Note that the concave lines connecting the three stations indicate the curvature of long lines, such as those in the illustration, on the state plane. The angles shown are observed values.

64.1. The following values are taken from the *Plane Coordinate Projection Tables—Colorado*, published by the U.S. Government Printing Office.

latitude	R (ft)	tabular difference for 1″ of latitude (ft)
39°41′	25,569,283.24	101.18217
42′	25,563,212.31	101.18283
43′	25,557,141.34	101.18350
44′	25,551,070.33	101.18400
45′	25,544,999.29	101.18467

What is the appropriate R value for the station labeled Capitol?

(A) 25,541,081.04 ft

(B) 25,547,152.08 ft

(C) 25,548,917.54 ft

(D) 25,554,988.58 ft

64.2. What is the value of θ for the station labeled Capitol?

(A) $-00°30'56''.39$
(B) $-00°20'10''.92$
(C) $+00°19'30''.81$
(D) $+00°19'35''.35$

64.3. What is the x-coordinate of station Capitol?

(A) 145,021.38
(B) 2,145,021.38
(C) 25,548,507.95
(D) 27,548,505.95

64.4. What is the y-coordinate of station Capitol?

(A) 609,803.31
(B) 687,312.94
(C) 694,546.79
(D) 706,091.46

64.5. What is the angular spherical excess in the figure created by Crown, Capitol, and Thornton 2?

(A) 0.4 sec
(B) 0.8 sec
(C) 1.2 sec
(D) 3.1 sec

64.6. What is the second-term, or θ', correction that would be applied at station Crown for the line Crown-Capitol?

(A) $-01''.2$
(B) $-00''.4$
(C) $+00''.9$
(D) $+01''.7$

64.7. What is the second-term, or θ', correction that would be applied at station Crown for the line Capitol-Crown?

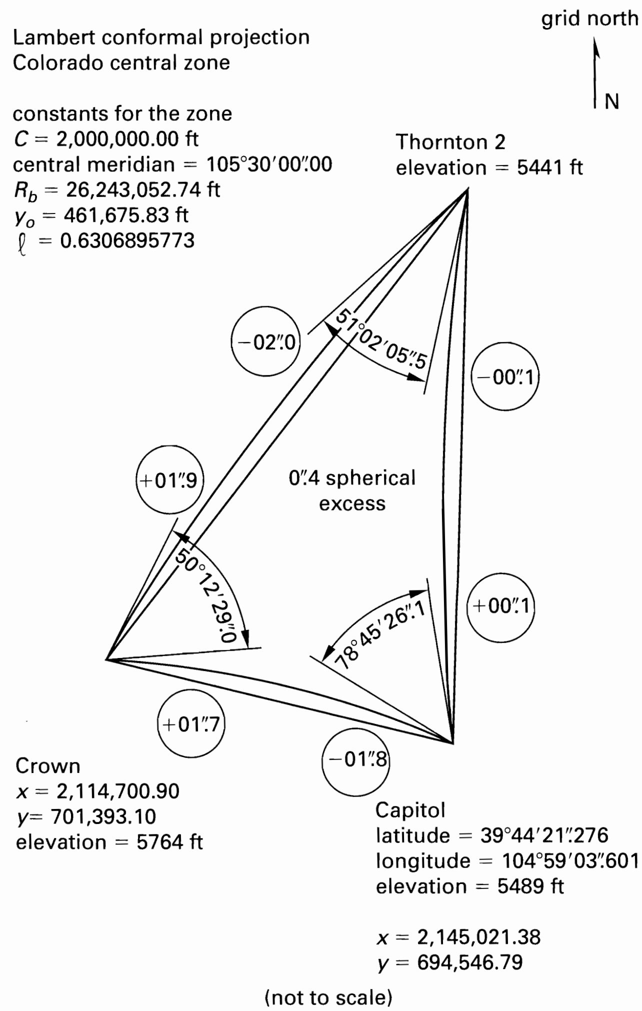
(A) $-0''.08$
(B) $-01''.8$
(C) $+01''.7$
(D) $+01''.9$

65. Given the value of ℓ for the Colorado central zone of 0.6306895773, what is the parallel of latitude for that zone along which the scale factor ratio is smallest?

(A) $38°27'00''.00$
(B) $39°06'03''.66$
(C) $39°33'21''.53$
(D) $39°45'00''.00$

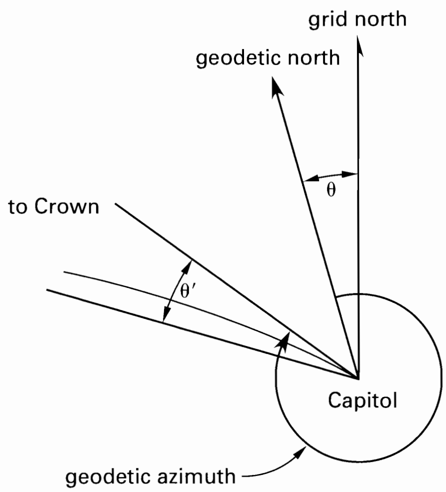
66. In the following illustration, the concave lines connecting the three stations indicate the curvature of long lines on the state plane. The angles shown are observed values. The angular values circled are the second-term, or θ', values.

Given this information, what are the correct values for the three interior angles of the figure after both second terms and spherical excess have been taken into consideration?



(A) $51°02'02''.3$
$78°45'26''.7$
$50°12'27''.5$
(B) $51°02'03''.5$
$78°45'27''.9$
$50°12'28''.7$
(C) $51°02'03''.6$
$78°45'28''.0$
$50°12'28''.8$
(D) $51°02'05''.5$
$78°45'26''.1$
$50°12'29''.0$

67. What is the geodetic azimuth from station Capitol to station Crown as shown in the following illustration?



(A) 257°16′35.″7
(B) 257°36′06.″5
(C) 282°43′26.″1
(D) 283°02′58.″7

68. The state plane coordinates of Thornton 2 in the Colorado central zone are

$$x = 2{,}146{,}262.93$$
$$y = 742{,}549.22$$

The constants for the zone are

$$C = 2{,}000{,}000 \text{ ft}$$
$$\text{central meridian} = 105°30'00''$$
$$R_b = 26{,}243{,}052.74 \text{ ft}$$
$$y_o = 461{,}675.83$$
$$\ell = 0.6306895773$$

The applicable tabular values are

latitude	R (ft)	tabular difference for 1″ of latitude (ft)
39°51′	25,508,572.22	101.18867
52′	25,502,500.90	101.18933
53′	25,496,429.54	101.19000
54′	25,490,358.14	101.19083
55′	25,484,286.69	101.19133

What is the latitude of station Thornton 2?
(A) 39°48′20.″99
(B) 39°51′37.″41
(C) 39°52′15.″59
(D) 39°54′29.″78

69. The state plane coordinates of Thornton 2 in the Colorado central zone are

$$x = 2{,}146{,}262.93$$
$$y = 742{,}549.22$$

The constants for the zone are

$$C = 2{,}000{,}000 \text{ ft}$$
$$\text{central meridian} = 105°30'00''$$
$$R_b = 26{,}243{,}052.74 \text{ ft}$$
$$y_o = 461{,}675.83$$
$$\ell = 0.6306895773$$

The value of θ for the station is $+00°19'43.''06$.

What is the longitude of Thornton 2?
(A) 104°32′12.″09
(B) 104°44′21.″87
(C) 104°56′55.″99
(D) 104°58′44.″18

70. The elevations and latitudes of Thornton 2 and 400 for the Colorado central zone are as follows.

For Thornton 2,
$$\phi = 39°52'15.''594$$
$$\text{elev} = 5441 ft$$

For 400,
$$\phi = 39°50'56.''090$$
$$\text{elev} = 5246 ft$$

The applicable tabular information is

ϕ	R (ft)	tabular difference 1″ ϕ (ft)	scale as a ratio
39°46′	25,538,928.21	101.18533	1.0000033
47′	25,532,857.09	101.18600	1.0000068
48′	25,526,785.93	101.18667	1.0000103
49′	25,520,714.73	101.18717	1.0000139
50′	25,514,643.50	101.18800	1.0000175
39°51′	25,508,572.22	101.18867	1.0000213
52′	25,502,500.90	101.18933	1.0000252
53′	25,496,429.54	101.19000	1.0000291
54′	25,490,358.14	101.19083	1.0000331
55′	25,484,286.69	101.19133	1.0000372

The distance measured between the two stations is 10,206.50 ft.

What is the grid distance between Thornton 2 and 400?

(A) 10,203.89 ft
(B) 10,204.13 ft
(C) 10,204.92 ft
(D) 10,206.74 ft

GOVERNMENT ADMINISTRATION OF STATE PLANE COORDINATE SYSTEMS

71. Which agency established the design of the state plane coordinate systems used in the U.S.?

(A) U.S. Geological Survey
(B) U.S. Coast and Geodetic Survey
(C) Bureau of Land Management
(D) Department of the Interior

72. As the transition from NAD27 to NAD83 continues, what organization is ultimately responsible for legalization of the necessary changes in the various state plane coordinate systems?

(A) National Geodetic Survey
(B) U.S. Geological Survey
(C) Federal Board of Surveys and Maps
(D) legislature of each state

73. Where are state plane coordinate systems available?

(A) Every state and possession of the U.S. has a state plane coordinate system.
(B) Thirty-seven states have state plane coordinate systems.
(C) Every state except Hawaii has a state plane coordinate system.
(D) Every public lands state has a state plane coordinate system.

74. Which of the following organizations publishes geographical and state plane coordinates in both NAD27 and NAD83 for its national network o f geodetic control stations?

(A) Bureau of Land Management
(B) Bureau of Reclamation
(C) Federal Geodetic Control Committee
(D) National Geodetic Survey

STANDARDS

75. In the geometric relative positioning accuracy standards for three-dimensional surveys, using space system techniques in the *Geometric Geodetic Accuracy Standards and Specifications for the Use of GPS Relative Positioning Techniques* published by the FGCC in 1988, the previously established first-, second-, and third-order classifications are found grouped under one of four primary orders. Which of the new primary orders in this publication includes these older classifications?

(A) order AA
(B) order A
(C) order B
(D) order C

76. The standards of accuracy for blue booking, as given in *Input Formats and Specifications of the National Geodetic Survey Data Base*, specify, among other things, that the data must be formatted correctly per the Federal Geodetic Control Subcommittee (FGCS), and meet which of the following minimum accuracy requirements?

(A) GPS; first-order
(B) conventional horizontal surveys; first-order
(C) conventional geodetic leveling; second-order, class II
(D) all of the above

77. The geometric standards described in the *Geometric Geodetic Accuracy Standards and Specifications for the Use of GPS Relative Positioning Techniques*, specify loop closures as part of office procedure for classifying GPS relative positioning networks, and are used to obtain a GPS network's initial estimates for internal consistency. However, the error of closure of these loops is only valid when an adequate number of baselines are involved. Which of the following has an INADEQUATE number of baselines for the order stipulated?

(A) For order AA, error of closure is valid only when four or more independently determined baselines, from four or more observing sessions, are included in the loop closure analysis.
(B) For order A, error of closure is valid only when two or more independently determined baselines, from three or more. observing sessions, are included in the loop closure analysis
(C) For order B, error of closure is valid only when two or more independently determined baselines, from two or more observing sessions, are included in the loop closure analysis.
(D) For order 1 and lower, error of closure is valid only when two or more independently determined baselines, from two or more observing sessions, are included in the loop closure analysis.

78. Which of the following items is NOT a part of the data quality report in the spatial data transfer standards (SDTS) established by USGS?

(A) completeness
(B) lineage
(C) positional accuracy
(D) data dictionary

79. Which of the following organizations publishes standards and specifications for the surveying of geodetic control networks?

(A) Federal Board of Surveys and Maps
(B) Bureau of Reclamation
(C) Federal Geodetic Control Committee
(D) U.S. Forest Service

Geodetic and Control Surveys Solutions

NORTH AMERICAN DATUMS

1. The North American Datum of 1927 (NAD27) is based on ellipsoidal parameters defined as the Clarke Spheroid of 1866.

A readjustment of the national network done to introduce Laplace azimuths yielded the geodetic positions now available on NAD27. The origin of that readjustment is designated as

$$\begin{aligned} \phi &= 39°13'26.''686\text{N} \\ \lambda &= -98°32'30.''506\text{E} \end{aligned}$$

The origin is located at Meades Ranch in Kansas, and the azimuth from Meades Ranch to Waldo is defined as 75°28′09.″64. The geoidal height is assumed to be zero, and NAD27 is not geocentric.

The answer is (D).

2. The North American Datum of 1983 (NAD83) is based on a geocentric origin. 250,000 points, including 600 stations whose positions had been determined by satellite geodesy, were used to constrain the datum to its geocentric origin.

NAD83 has not completely replaced NAD27 in the U.S. and is not used throughout the western hemisphere. NAD83 is used in the U.S., Canada, Mexico, and Central America.

The answer is (A).

3. The shape of the earth is represented in NAD83 by an ellipsoid of revolution that is biaxial and rotated about its minor axis. The actual shape of the earth is oblate—that is, flattened at the poles. Rotation approximates the shape.

The answer is (A).

4. Local distortions caused by low-quality original observations in NAD27 coordinates are one source of the difficulty involved in transforming coordinates from that datum to NAD83. Approximate methods of transformation can be designed by computing local translation components based on stations with three-dimensional coordinates common to both systems, but there is no universal one-step mathematical approach available. The most reliable transformations are based on a return to the original observations and the performance of a readjustment of the entire region.

The answer is (A).

5. Clarke 1866 is the reference ellipsoid for NAD27. GRS80 is the reference ellipsoid for NAD83. The WGS84 ellipsoid is virtually identical to the GRS80, but there is a slight difference in the flattening, probably due to the lack of sufficient significant figures in its original computation.

The answer is (A).

6. One way to understand the geoid is to imagine that trenches have been cut through the land masses of the earth, and water has been allowed to flow into them. The surface assumed by the water would then approximate the surface known as the *geoid*, which would closely resemble the ocean's surface if they were completely still. The geoid is often called an *equipotential surface*. In other words, the direction of gravity is always perpendicular to the geoid.

The answer is (D).

7. The flattening associated with a reference ellipsoid is conventionally expressed as

$$f = \frac{a - b}{a}$$

The answer is (B).

8. The geoid is defined by the earth's gravity. The unequal distribution of the mass of the earth causes irregularity in the force and direction of gravity; consequently, the geoid is also irregular.

The answer is (D).

9. The Sea Level Datum of 1929 was renamed in May 1976; now it is called the National Geodetic Vertical Datum of 1929. One reason for the new name is that the datum does not accurately represent mean sea level or any equipotential surface. The datum was based on observed heights of mean sea level at 26 tidal stations, 21 in the U.S. and 5 in Canada, along the Atlantic, Gulf, and Pacific coasts. Additionally, more than 100,000 km of leveling established benchmarks throughout the U.S.

The answer is (D).

10. While level surfaces may be considered parallel for surveying a limited area, in fact, they are not. The geoid, a close representation of a level surface, is not only discontinuous over variations of density in the earth, but is subject to a general convergence as well. The relative distance between two level surfaces will decrease from the equator to the poles as a consequence of the increase in gravity.

The answer is (D).

11. The vertical readjustment, known as the North America Datum of 1988 (NAVD88), began in the 1970s. It addressed the elevations of benchmarks all across the United States. The effort included field work that replaced destroyed and disturbed benchmarks, and over 50,000 mi of leveling was redone before NAVD88 was ready in June of 1991. The elevations stamped on monuments set in the 1940s would likely be in the National Geodetic Vertical Datum 1929 (NGVD29), not NAVD88. The differences between benchmark elevations determined in NGVD29 compared with the elevations of the same benchmarks in NAVD88 vary from approximately −1.3 ft in the East, to approximately +4.9 ft in the West for the 48 coterminous states of the United States.

The answer is (C).

12. Concerning the acceleration of gravity, the average acceleration of a falling object is approximately 978 gals (978 cm/sec^2 or 32.09 ft/sec^2) at the equator. At the poles, the acceleration of a falling object increases to approximately 984 gals (984 cm/sec^2 or 32.28 ft/sec^2). The acceleration of a falling object at 45° latitude is between these two values at 980.6199 gals. This value is sometimes called *normal gravity.*

The length of a degree of longitude and the length of a degree of latitude is approximately the same in the vicinity of the equator—about 60 nautical mi (111 km or 69 mi). However, a degree of longitude gets shorter as it nears either pole. At two-thirds of the distance from the equator to the pole (i.e., 60° north or south latitude), a degree of longitude is about 55.5 km (34.5 mi) long—half the length it had been at the equator. As one proceeds northward or southward, a degree of longitude continues to shrink until it fades to nothing.

On the other hand, lines of latitude do not converge; they are always parallel with the equator. In fact, as one approaches the poles where a degree of longitude becomes small, a degree of latitude grows slightly. This small increase occurs because the ellipsoid gets flatter near the poles. If the earth was a sphere, this flattening would not occur and a degree of latitude would always be as long as it is at the equator—110.6 km (68.7 mi). However, since the earth is an oblate spheroid as Newton predicted, a degree of latitude gets longer at the poles. It grows to about 111.7 km (69.4 mi).

The answer is (D).

13. At the given coordinates, one second of latitude is approximately 100 ft, and one ten thousandth of a second of latitude is approximately 0.01 ft. One second of longitude is approximately 80 ft, and one ten thousandth of a second of longitude is approximately 0.008 ft.

The answer is (A).

14. The reference ellipsoids for both NAD83 and NAD-27 are biaxial; that is, they have two axes. A triaxial ellipsoid has three axes, an idea that has been around a long time. In 1860, Captain A. R. Clarke wrote to the Royal Astronomical Society stating, "The earth is not exactly an ellipsoid of revolution. The equator itself is slightly elliptic." Therefore, the length of the semimajor axis is not constant in triaxial ellipsoids. A triaxial ellipsoid has flattening at both the poles and the equator so that the length of the semimajor axis varies along the equator. The Krassovski ellipsoid, also known as Krasovsky ellipsoid, is triaxial.

The answer is (C).

15. The concrete manifestation of a datum is known as its *realization.* The realization of a datum is the actual marking and collection of coordinates on stations throughout the region covered by the datum. In other words, it is the creation of the physical network of reference points on the earth's surface.

The answer is (B).

16. The National Geodetic Survey (NGS) and the Geodetic Survey of Canada set about the task of attaching and orienting the GRS80 ellipsoid to the actual surface of the earth, as defined by the best positions available at the time. It took more than 10 years to readjust and redefine the horizontal coordinate system of North America into what is now the North American Datum of 1983 (NAD83). With the surveying capability of GPS and the new NAD83 reference system in place, NGS began the long process of a nationwide upgrade of their control networks. This upgrade, known as the National Geodetic Reference System (NGRS), includes three networks. A horizontal network provides geodetic latitudes and longitudes in the North American Datums. A vertical network furnishes heights, also known as elevations, in the National Geodetic Vertical Datums (NGVD). A gravity network supplies gravity values in the U.S.'s absolute gravity reference system. Any particular station may have its position defined in one, two, or all three networks.

The answer is (C).

17. Once the initial point and directions were fixed, the entire orientation of NAD27 was established—including the center of the reference ellipsoid. Its center was imagined to reside somewhere around the earth's center of mass. However, the two points were not coincident, nor were they intended to be; therefore, NAD27 does not use a geocentric ellipsoid. In the period before space-based geodesy was tenable, such a regional datum was not unusual. The Australian Geodetic Datum 1966, the Datum Européen 1950, and the South American Datum 1969 among others, were also designed as nongeocentric systems.

The answer is (D).

18. The creations of High Accuracy Reference Networks (HARNs) are cooperative ventures between NGS and individual states, and often include other organizations as well. With heavy reliance on GPS observations, these networks are intended to provide extremely accurate, vehicle accessible, regularly spaced control points with good overhead visibility. To ensure coherence, when GPS measurements are complete, they are submitted to NGS for inclusion in a statewide readjustment of the existing NGRS covered by the state. Coordinate shifts of 0.3 m to 1.0 m from NAD83 values have been typical in these readjustments.

The answer is (D).

19. Unavoidable forces cause the mean sea level (MSL) to deviate up to one, even two meters from the geoid. This fact is frequently mentioned to emphasize the inconsistency of the geoid's original definition as offered by J.B. Listing in 1872. Listing thought the geoidal surface was equivalent to MSL; however, MSL and the geoid are not the same. While Listing's definition does not stand up to today's scrutiny, it can still be instructive.

Just as the geoid does not precisely follow MSL, neither does it exactly correspond with the topography of the earth's dry land. Instead, the geoid is similar to the earth's terrestrial surface, as it is bumpy and has similar peaks and valleys. If the solid earth did not have internal density anomalies, the geoid would be smooth and almost exactly ellipsoidal. If this were the case, the reference ellipsoid would fit the geoid almost perfectly. However, like the earth itself, the geoid defies such mathematical consistency and departs from true ellipsoidal form by as much as 100 m in some places.

The answer is (D).

MAP PROJECTIONS

20. The earth is curved, and maps are flat. If the graticule, or grid, of a map is to correspond with the parallels of latitude and meridians of longitude on the terrestrial surface, an orderly method of transference must be adopted. There are many map projections that accomplish this; each has unique characteristics.

The answer is (B).

21. The Lambert projection and the transverse Mercator projections form the foundation for nearly all of the state plane coordinate systems. However, zone 1 of the Alaska system is based on an oblique transverse Mercator projection.

The answer is (D).

22. The difficulty of representing the earth's surface on a flat map can be solved by projecting the information from an ellipsoidal representation of the earth onto some surface that may be unrolled or developed, such as a cone or cylinder. These conic sections (if a cylinder may be so considered) can each be cut along an element and neatly flattened, minimizing distortion. Distortion can never be completely eliminated, however.

The answer is (C).

23. Some map projections allow for the angles between two curves on the spheroidal surface to be preserved on the map. This property, known as *conformality*, provides for the maintenance of elementary shapes on the map.

The answer is (D).

24. A rhumb line, or loxodrome, appears to be a straight line on the Mercator projection. It crosses each meridian at a constant angle, but does not follow a great circle—the shortest path between two points.

The answer is (A).

25. The arc of a great circle will be a straight line on a gnomonic map projection, which is generated on a plane tangent to the ellipsoid at a single point.

The answer is (C).

26. In the State Plane Coordinate System (SPCS) the direction known as grid north is always parallel to the central meridian for the zone. In SPCS, north is grid north and the lines of the grid are parallel to each other. They must also be parallel to one another and the central meridian of the zone, so clearly geodetic north and grid north are not the same. In fact, grid north and geodetic north only coincide on the central meridian—everywhere else in the zone they diverge from one another, creating an angle between them. In SPCS27, the angle for the Lambert Conic project was symbolized with the Greek letter theta, θ; in the Transverse Mercator projection, it was given the symbol delta alpha, $\Delta\alpha$. However, in SPCS83, convergence is symbolized with gamma, γ, in both the Lambert Conic and the Transverse Mercator projections.

The answer is (D).

27. There have been changes in the distances between the SPCS zones and their origins. In the old SPCS27 arrangement, the y-axis was 2,000,000 ft west from the central meridian in the Lambert Conic projection, and 500,000 ft in the Transverse Mercator projection. In the SPCS83 design, those constants changed so that the most common values became 600,000 m for the Lambert Conic projection, and 200,000 m for the Transverse Mercator projection. However, there is a good deal of variation in these numbers from state to state and from zone to zone.

It is important to note that the fundamental unit for SPCS27 is the U.S. survey foot and for SPCS83 it is the meter. The original goal with SPCS27 was to keep each zone small enough to ensure that the scale distortion was 1 part in 10,000 or less. However, when the SPCS83 was designed, some states did not maintain that scale. In five states, some SPCS27 zones consolidated into one zone, or added to adjoining zones. In three of those states, the result was one single large zone. Therefore, because the area covered by these single zones became so large, they were not limited by the 1 part in 10,000 standard.

This is not the first time the goal of 1 part in 10,000 was changed. In Texas, the original scale factor was allowed to be slightly above the ratio of 1 part in 10,000 so that the state was completely covered with five zones. In 1933, among the guiding principles was covering the states with as few zones as possible and having zone boundaries follow county lines.

The answer is (D).

THE LAMBERT PROJECTION

28. Conformality is the characteristic of the Lambert projection that preserves the shape of small figures as they are transformed from the ellipsoid to the mapping plane. The Lambert projection is a conic projection; that is, the developable surface employed is imagined to be a cone.

The answer is (A).

29. The Greek letter θ is used in the Lambert projection to indicate the mapping angle in the State Plane Coordinate System 1927 (SPCS27).

The answer is (D).

30. The secant cone intersects the ellipsoid at two lines of exact scale. This design allows the scale distortion to be minimized. Most of the mapping plane is actually between the standard parallels and, therefore, beneath the surface of the ellipsoid.

The answer is (D).

31. The scale factor in a Lambert projection is dependent on the latitude of a position.

The answer is (C).

32. The standard parallels of a secant Lambert projection may be visualized as the intersection of the plane of the cone with the surface of the spheroid. Any distance along a standard parallel would be exactly the same on the spheroid as on the map.

The answer is (D).

33. The conic Lambert projection represents parallels of latitude as arcs of nearly equally spaced concentric circles. Meridians of longitude are shown as straight lines converging at the pole.

The answer is (A).

34. Twenty-nine states use the Lambert projection exclusively as the basis of their state plane coordinate systems—Arkansas, California, Colorado, Connecticut, Iowa, Kansas, Kentucky, Louisiana, Maryland, Massachusetts, Michigan, Minnesota, Montana, Nebraska, North Carolina, North Dakota, Ohio, Oklahoma, Oregon, Pennsylvania, South Carolina, South Dakota, Tennessee, Texas, Utah, Virginia, Washington, West Virginia, and Wisconsin.

The answer is (C).

35. The target for maximum scale distortion is 1 part in 10,000. States that extend less than 158 mi north-south meet this goal. For example, the maximum scale in the Connecticut Coordinate System is about 1:40,000 along its southern and northern boundaries. On the other hand, the coverage of Texas by five zones was accomplished only by allowing distortion to go slightly more than 1:10,000.

The answer is (B).

36.1. Most frequently, the area between the standard parallels is approximately 105 mi, or four-sixths of the total zone. In other words, two-thirds of the area mapped is within the spheroid. One-sixth, or about 26 mi of the zone, is north of the northerly standard parallel and one-sixth is south of the southerly standard parallel. These latter areas are outside or above the spheroid.

The answer is (D).

36.2. The usual alignment of the axis of the imaginary cone used in the Lambert projection is along the extension of the earth's polar axis.

The answer is (B).

THE TRANSVERSE MERCATOR PROJECTION

37. The transverse Mercator projection is distinct from the Mercator projection in that the axis of the cylindrical surface is imagined to be perpendicular to the axis of the spheroid.

The answer is (B).

38. The variation of the scale in a transverse Mercator projection is based on changes in longitude, rather than latitude. The scale is constant along the central meridian of a transverse Mercator projection.

The answer is (D).

39. The symbol used in the transverse Mercator projection to indicate the mapping angle, or convergence, is $\Delta\alpha$, in the State Plane Coordinate System 1927 (SPCS27).

The answer is (C).

40. The cylinder used to generate a transverse Mercator-based state plane coordinate system intersects the spheroid along two lines that describe ellipses on the spheroid. The lines are the lines of strength of the developed map. The scale factor is 1 along these lines; they are equidistant from, and parallel with, the central meridian of the zone.

The answer is (B).

41. The UTM projection provides a worldwide system of coordinates in meters. Five different reference ellipsoids are used. They are the Clarke spheroids of 1866 and 1880, the international ellipsoid, the Bessel ellipsoid, and the Everest ellipsoid. The Clarke spheroid of 1866 is presently used in North America.

The answer is (D).

42. The Universal Transverse Mercator (UTM) coordinate system differs significantly from the Transverse Mercator system. The Transverse Mercator coordinate system is used in the State Plane Coordinate System, which was first designed by Dr. Oscar Adams, of the Division of Geodesy at the United States Coast and Geodetic Survey, assisted by Charles Claire. UTM was originally a military system that covered the globe.

The UTM secant projection gives approximately 180 km between the lines of exact scale where the cylinder intersects the ellipsoid. The scale factor grows from 0.9996 along the central meridian of a UTM zone to 1.00000 at 180 km to the East and West. SPCS zones are usually limited to about 158 mi and, therefore, have a smaller range of scale factors than do the UTM zones. In state plane coordinates, the scale factor is usually about 1 part in 10,000. In UTM coordinates it can be as large as 1 part in 2500. The 60 UTM zones nearly cover the earth, except the polar regions which are covered by two azimuthal polar zones called the Universal Polar Stereographic (UPS) projection.

When NAD83 was established, the National Geographic Society (NGS), which replaced the U.S. Coast and Geodetic Survey (USC&GS), mandated that the meter become the official unit of all the published coordinate values. However, in 1986, NGS announced that it would augment the state plane coordinate publications that were in meters with coordinates for the same stations in feet. Deciding whether to use the international foot or the U.S. survey foot would be determined by the state legislation in which the station was found.

Currently, 11 states are using the U.S. survey foot and 6 are using the international foot. 14 states do not specify the version of the foot that is official for their SPCS, and the remaining 19 states have no legislation on the state plane coordinates.

The answer is (B).

43. An ellipsoidal height, also known as geodetic height, and a geoid height are measured along a line perpendicular to the ellipsoid of reference to a point on the earth's surface. An orthometric height is measured along a plumb line from the geoid to a point on the surface of the earth.

The answer is (D).

44. The reciprocal of the eccentricity is usually not paired with the semimajor axis to define a reference ellipsoid.

The definition of a reference ellipsoid is accomplished with two numbers. It usually includes the semimajor axis and one of the other answer choices given. The following are some common pairs of constants: the semimajor and semiminor axes in meters, the semimajor axis in meters with the flattening or its reciprocal, and the semimajor axis and the eccentricity.

The answer is (D).

STATE PLANE COORDINATE SYSTEMS

45.1. A constant of 500,000 ft is currently used in all of the states employing the transverse Mercator projection. This arbitrary constant between the y-axis and the central meridian of each zone prevents negative x values in the coordinates of NAD27. However, as states convert coordinate positions to NAD83, this constant will be changed.

The answer is (A).

45.2. The conversion of state plane coordinate positions to NAD83 will involve a change in the arbitrary distance between the y-axis and the central meridian of transverse Mercator zones. Recommendations for the change include the expression of the now standard 500,000 ft in meters, a change from 500,000 ft to 300,000 ft, and a change from 500,000 ft to 700,000 ft.

The objective is to avoid any confusion of NAD27 with NAD83 coordinate positions. The conversion of feet to meters is a bit problematic since some states use the U.S. survey foot, which is 0.3048006 of a meter, while some prefer to use the international foot, which is 0.3048000 of a meter. No single value is used universally, as was the 500,000 ft value. All of the quantities shown have been proposed in various states and others are likely to be proposed.

The answer is (D).

45.3. The line labeled IJ represents geodetic north at station B. Line GH represents grid north and is parallel to the central meridian.

The answer is (D).

45.4. The symbols most consistently used in the state plane coordinate systems based on the transverse Mercator projection are C $= y_o$, D $= \Delta\phi$, and E $=$ y-coordinate. The y-coordinate of station B is the sum of y_o, called tabular y, and the quantity $\Delta\phi$. Note that the parallel of latitude through station B intersects the central meridian somewhat to the south of the line labeled x'.

The answer is (A).

45.5. The spheroidal perpendicular is the distance from the central meridian along a grid line to the station under consideration, and is usually symbolized by x'. The length of the spheroidal perpendicular is

$$K\left(S_g + \frac{S_g^3}{6\rho^2}\right)$$

S_g is the actual geodetic length of the perpendicular, ρ is the average radius of the spheroid, and K is the scale factor.

The answer is (B).

45.6. East of the central meridian of a zone, $\Delta\alpha$, the convergence (or mapping angle) is positive (+); west of the central meridian, the value is negative (−).

The answer is (C).

46.1. A constant of 2,000,000 ft is currently used in all of the states employing the Lambert projection. This arbitrary constant between the y-axis and the central meridian of each zone prevents negative x values in the coordinates of NAD27. However, as states convert coordinate positions to NAD83, this constant will be changed.

The answer is (D).

46.2. The usual symbol for the mapping angle, or convergence, in the Lambert projection is the Greek letter θ. It is considered to be positive to the east of the central meridian and negative to the west.

The answer is (B).

46.3. The distance labeled A is known as x'. It can also be represented by the expression $R\sin\theta$.

The answer is (A).

46.4. The distance labeled E is the y-coordinate of station B. The distance from the apex of the cone to the grid line through station B is equal to $R\cos\theta$. The distance labeled F is usually symbolized R_b.

The answer is (D).

46.5. The central meridian is the name usually given to the longitudinal line chosen near the center of the zone.

The answer is (C).

46.6. The value of the mapping angle, θ, is sometimes positive and sometimes negative. Therefore, the correct formulas for the x- and y-coordinates in the Lambert projection are

$$x = R\sin\theta + C$$
$$y = R_b - R\cos\theta$$

The answer is (D).

47. The constant C is 2,000,000 ft for each zone, and each zone has a unique origin for its coordinates. A third constant value, known as R_b, is the distance from the apex of the cone to its x-axis.

The answer is (A).

48. The variables that are dependent on latitude in the Lambert projection are: R, the radius from the apex of the cone to a given station; θ, the convergence; and the scale factor. In a transverse Mercator projection, the geodetic multipliers H and V, y_o, and the small correction a vary with the changes in latitude.

The answer is (C).

49. Distortion of one part in 10,000 implies a scale factor of 0.9999 at the lower limit and 1.0001 at the upper limit. While some state plane coordinate zones may exceed these limits, the objective is to stay within them whenever possible.

The answer is (C).

50. The developable surface of the mapping plane is below the spheroid between the standard parallels of a Lambert secant projection. Therefore, the distances on the spheroid are always reduced when they are projected onto the mapping plane. In other words, the scale factor is always less than 1 between the standard parallels.

The answer is (C).

51. The distance from a given point to the central meridian, also known as the *spheroidal perpendicular*, is the basis for the derivation of the scale factor in the transverse Mercator projection. The spheroidal perpendicular is symbolized by x'.

The answer is (D).

52. The cylinder is above the spheroid outside the lines of its intersection, which are the lines of exact scale. The distances on the spheroid are increased when they are projected onto the developable surface. Therefore, the scale factor is greater than 1.

The answer is (A).

53. The combination, or grid, factor is used to move directly from the earth's surface to the state plane in one step. This factor is the product of the scale, or K, factor and the sea-level factor.

The answer is (D).

54. The mean radius of the spheroid over the coterminous U.S. has been considered as 20,906,000 ft for many years. This approximation is adequate for many applications, although the actual figure varies as much as 50,000 ft across the 48 coterminous states.

The answer is (B).

55. The scale factor varies with the latitude in the Lambert projection and with the longitude in the transverse Mercator projection. Large changes in these elements of the scale factor, especially in long lines, may require the use of the weighted mean in calculating the scale factor.

The answer is (B).

56. The ϕ_o latitude is near, but not precisely at, the center of the zone. The latitude of the line can be found as $\sin^{-1}\ell$. The scale factor ratio reaches its minimum along the ϕ_o line, and the geodetic lines projected onto the state plane in the zone are concave toward it.

The answer is (D).

57. In the Lambert projection, the most common symbol for the second-term correction is θ'. The second term is a compensation applied to the direction of long lines on the state plane that would otherwise retain a slight curvature toward the center of the zone—that is, toward the parallel of latitude known as ϕ_o.

The answer is (B).

58. The formula for conversion of a geodetic azimuth to a grid azimuth is

$$\text{grid azimuth} = \text{geodetic azimuth} - \theta$$

This conversion ignores the effect of the second term since a relatively short line is involved.

The answer is (B).

59. The expression $\Delta\lambda'' \sin\phi + g$ is equivalent to $\Delta\alpha$, the mapping angle, in the transverse Mercator projection. The change in longitude in seconds, $\Delta\lambda''$, multiplied by the sine of the latitude is adjusted by the small quantity g, normally found in published tables.

The answer is (D).

60. θ is positive to the east of the central meridian and negative to the west. Its absolute value is always less than the change in longitude from the central meridian.

The answer is (D).

61. The following formulas are usually given in state plane projection tables.

$$\Delta\lambda = \frac{\theta}{\ell}$$
$$\theta = \Delta\lambda\ell$$
$$\tan\theta = \frac{x'}{R_b - y}$$
$$\theta = \tan^{-1}\left(\frac{x'}{R_b - y}\right)$$

The answer is (D).

SHORT GEODETIC CALCULATIONS

62. Since the geodetic azimuth is measured clockwise from south, subtract 180° to find the geodetic azimuth from north.

$$\begin{array}{r} 186°15'22.''21 \\ -180°00'00.''00 \\ \hline 06°15'22.''21 \end{array}$$

The formula for finding the grid azimuth of short lines is

$$\begin{aligned} \text{grid azimuth} &= \text{geodetic azimuth} - \theta \\ &= 06°15'22.''21 - (+00°40'21.''85) \\ &= 05°35'00.''36 \end{aligned}$$

The answer is (A).

63. There is not enough information given to answer this question. While the grid azimuth will be precisely 180° different at station Exeter (212°32′14.″1) from its value at station Abott (32°32′14.″1), the same cannot be said of the geodetic azimuth. Without the value of the mapping angle at station Abott or some information from which it may be derived, the question cannot be answered.

The answer is (D).

64.1. The R value for a particular station is the distance from the apex of the cone to that station in feet. One way to derive its value is to use the tabular difference for 1″ of latitude given.

First, find the difference in seconds of latitude from the next smaller minute given.

$$\begin{array}{rr} \text{latitude of station Capitol} = & 39°44'21.''276 \\ & -39°44'00.''000 \\ \hline \text{difference in seconds} = & 21.''276 \end{array}$$

Next, multiply this difference by the tabular difference for 1″ of latitude to find the difference between the R value at latitude 39°44′00.″000 and at latitude 39°44′21.″276.

$$(21.''276)(101.18400 \text{ ft}) = 2152.79 \text{ ft}$$

Finally, subtract this difference from the R value given for the next smaller latitude.

39°44′	25,551,070.33 ft	101.18400 ft
	−2152.79 ft	
39°44′21.″276	25,548,917.54 ft	
39°45′	25,544,999.29 ft	101.18467 ft

The answer is (C).

64.2. There is more than one way to calculate the θ angle from the longitude of a station. One way is to use the following relationship.

$$\theta = \Delta\lambda\ell$$

The symbol $\Delta\lambda$ refers to the change in longitude from the central meridian of the zone, which in this case is from 105°30′00″.

$$\begin{array}{rr} \text{central meridian} = & 105°30'00.''000 \\ \lambda \text{ of Capitol} = & -104°59'03.''601 \\ \hline \Delta\lambda = & +00°30'56.''399 \end{array}$$

The symbol ℓ indicates the sine of the apex angle for the zone. It is shown in the illustration as 0.6306895773.

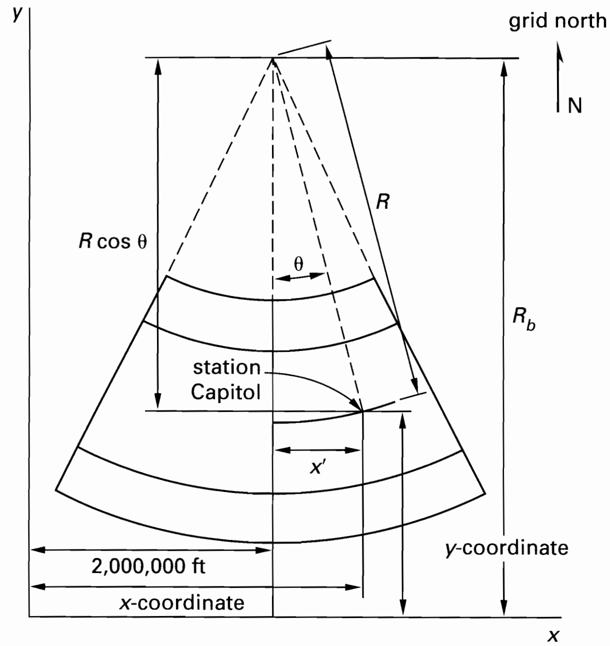
$$\begin{aligned} \theta &= \Delta\lambda\ell \\ &= (+00°30'56.''399)(0.6306895773) \\ &= +00°19'30.''81 \end{aligned}$$

The answer is (C).

64.3. The value of θ for station Capitol is +00°19′30.″8115, and the value of R is 25,548,917.54 ft. These two quantities are sufficient to find the value of the x-coordinate, using the following formula.

$$x = R\sin\theta + C$$

C is the constant 2,000,000 ft between the central meridian and the y-axis. The following figure illustrates these relationships.



$$\begin{aligned} x &= R\sin\theta + C \\ &= (25{,}548{,}917.54 \text{ ft})(\sin +00°19'30''\!.8115) \\ &\quad + 2{,}000{,}000 \text{ ft} \\ &= 145{,}021.38 \text{ ft} + 2{,}000{,}000 \text{ ft} \\ &= 2{,}145{,}021.38 \text{ ft} \end{aligned}$$

The answer is (B).

64.4. The value of θ for station Capitol is $+00°19'30''\!.8115$, and the value of R is 25,548,917.54 ft. These two quantities are sufficient to find the value of the y-coordinate, using the following formula.

$$y = R_b - R\cos\theta$$

R_b is the constant for the zone. The value of R_b for the central zone of Colorado is 26,243,052.74 ft, as shown in the illustration of stations Crown, Capitol, and Thornton 2.

$$\begin{aligned} y &= R_b - R\cos\theta \\ &= 26{,}243{,}052.74 \text{ ft} \\ &\quad - (25{,}548{,}917.54 \text{ ft})(\cos +00°19'30''\!.8115) \\ &= 26{,}243{,}052.74 \text{ ft} - 25{,}548{,}505.95 \text{ ft} \\ &= 694{,}546.79 \text{ ft} \end{aligned}$$

The answer is (C).

64.5. The area of the figure can be used to find the spherical excess. Each 75.6 mi^2 included in the figure corresponds to approximately 1 sec of spherical excess. The area of the figure can be found as follows.

For Crown,

$$x = 2{,}145{,}021.38$$
$$y = 694{,}546.79$$

For Capitol,

$$x = 2{,}114{,}700.90$$
$$y = 713{,}393.10$$

$$\begin{aligned} \text{distance from Crown to Capitol} &= \text{distance } a \\ &= 31{,}083.81 \text{ ft [grid]} \\ \text{angle at Crown} &= \text{angle B} = 50°12'29''\!.0 \\ \text{angle at Capitol} &= \text{angle C} = 78°45'26''\!.1 \\ \text{angle at Thornton 2} &= \text{angle A} = 51°02'05''\!.5 \end{aligned}$$

Therefore, the area of the figure is

$$\begin{aligned} \text{A} &= \frac{a^2 \sin \text{B} \sin \text{C}}{\sin \text{A}} \\ &= \frac{(31{,}083.81 \text{ ft})^2(\sin 50°12'29''\!.0)(\sin 78°45'26''\!.1)}{\sin 51°02'05''\!.5} \\ &= \frac{(966{,}203{,}244.1 \text{ ft}^2)(0.753628393)}{0.777528722} \\ &= \frac{728{,}158{,}198.5 \text{ ft}^2}{0.777528722} \\ &= 936{,}503{,}280.1 \text{ ft}^2 \end{aligned}$$

Convert to square miles.

$$\frac{936{,}503{,}280.1 \text{ ft}^2}{\left(5280 \frac{\text{ft}}{\text{mi}}\right)^2} = 33.6 \text{ mi}^2$$

$$\begin{aligned} \text{spherical excess} &= \frac{33.6 \text{ mi}^2}{75.6 \frac{\text{mi}^2}{\text{sec}}} \\ &= 0.4 \text{ sec} \end{aligned}$$

The answer is (A).

64.6. The second-term correction is an angular value that is applied to long lines, generally lines of more than 5 mi in length. The line Crown-Capitol is nearly 6 mi long. The second-term correction is an accommodation of the residual curvature present in such lines even after the development of the mapping surface. The formula for finding the second-term correction in a Lambert projection is

$$\theta' = \left(\frac{x_2 - x_1}{2\rho_o^2 \sin 1''}\right)\left(y_1 - y_o + \frac{y_2 - y_1}{3}\right)$$

x_1, y_1 and x_2, y_2 are the coordinates of the beginning and the end of the line in question, respectively. y_o is the y-coordinate of the parallel of latitude near the center of the zone, which is a constant for each zone. The y_o value for the central zone of Colorado is 461,675.83 ft.

The quantity $1/(2\rho_o^2 \sin 1'')$ is also a constant for each zone and is 2.359×10^{-10} in the central zone of Colorado. Substitute the appropriate values into the formula.

For Crown,

$$x_1 = 2,145,021.38$$
$$y_1 = 694,546.79$$

For Capitol,

$$x_2 = 2,114,700.90$$
$$y_2 = 713,393.10$$

$$\begin{aligned}\theta' &= \left(\frac{x_2 - x_1}{2\rho_o^2 \sin 1''}\right)\left(y_1 - y_o + \frac{y_2 - y_1}{3}\right)\\ &= \left(\frac{2{,}145{,}021.4 - 2{,}114{,}700.9}{2\rho_o^2 \sin 1''}\right)\\ &\quad \times \left(701{,}393.1 - 461{,}675.8 + \frac{694{,}546.8 - 701{,}393.10}{3}\right)\\ &= (30{,}320.5)(0.0000000002359)\left(239{,}717.3 + \frac{-6846.3}{3}\right)\\ &= (0.000007153)(239{,}717.3 + (-2282.1))\\ &= (0.000007153)(237{,}435.2)\\ &= 01''.7\end{aligned}$$

The answer is (D).

64.7. The calculation for finding the second-term correction for a long line can be simplified somewhat through expression of the numbers involved with exponents of 10. For example, the value of $(1/2\rho_o^2 \sin 1'')$ for the central zone of Colorado can be expressed as 2.359×10^{-10} instead of 0.0000000002359. The coordinates of the points Crown and Capitol can be simplified in the same manner.

For Capitol,

$$x_1 = 21.450 \times 10^5$$
$$y_1 = 6.945 \times 10^5$$

For Crown,

$$x_2 = 21.115 \times 10^5$$
$$y_2 = 7.014 \times 10^5$$

Similarly, the constant y_o can be expressed as 4.617×10^5.

$$\begin{aligned}\theta' &= \left(\frac{x_2 - x_1}{2\rho_o^2 \sin 1''}\right)\left(y_1 - y_o + \frac{y_2 - y_1}{3}\right)\\ &= \left(\frac{21.115 \times 10^5 - 21.450 \times 10^5}{2\rho_o^2 \sin 1''}\right)\\ &\quad \times \left(\begin{array}{l}6.945 \times 10^5 - 4.617 \times 10^5\\ \quad + \dfrac{7.014 \times 10^5 - 6.945 \times 10^5}{3}\end{array}\right)\\ &= (-0.335 \times 10^5)(2.359 \times 10^{-10})\\ &\quad \times \left(2.328 \times 10^5 + \frac{0.069 \times 10^5}{3}\right)\\ &= (-0.335 \times 10^5)(2.359 \times 10^{-10})(2.351 \times 10^5)\end{aligned}$$

When multiplying, add exponents.

$$\begin{aligned}\theta' &= (-0.335 \times 10^5)(5.546 \times 10^{-5})\\ &= -01''.8\end{aligned}$$

The answer is (A).

65. The latitude crossing the region where the spheroid is farthest outside the cone is the line where the scale factor ratio is smallest. The ℓ value, a constant for each zone, is the sine of that latitude.

$$\sin^{-1} 0.6306895773 = 39^\circ 06' 03''.66$$

The answer is (A).

66. The second terms and the spherical excess are given in the illustration. Each angle may be corrected individually.

The angle at Thornton 2 is

$$\begin{aligned}\text{observed} &= 51^\circ 02' 05''.5\\ \theta' &= +(-02''.0)\\ &\quad -(-00''.1)\\ \text{one-third of spherical excess} &= -(+00''.13)\\ &\quad \overline{51^\circ 02' 03''.47}\end{aligned}$$

Rounded to the nearest tenth of a second, this value is $51^\circ 02' 03''.5$.

The angle at Capitol is

$$\begin{aligned}\text{observed} &= 78^\circ 45' 26''.1\\ \theta' &= +(+00''.1)\\ &\quad -(-01''.8)\\ \text{one-third of spherical excess} &= -(+00''.13)\\ &\quad \overline{78^\circ 45' 27''.87}\end{aligned}$$

Rounded to the nearest tenth of a second, this value is $78^\circ 45' 27''.9$.

The angle at Crown is

$$
\begin{array}{rr}
\text{observed} = & 50^\circ 12' 29''.0 \\
\theta' = & +(+01''.7) \\
 & -(+01''.9) \\
\text{one-third of spherical excess} = & -(+00''.13) \\
\hline
 & 50^\circ 12' 28''.67
\end{array}
$$

Rounded to the nearest tenth of a second, this value is $50^\circ 12' 28''.7$.

The answer is (B).

67. The grid azimuth from Capitol to Crown, $282^\circ 43' 26''.1$, may be found by inversing the grid coordinates.

For Crown,

$$x = 2,145,021.38$$

$$y = 694,546.79$$

For Capitol,

$$x = 2,114,700.90$$

$$y = 713,393.10$$

The mapping angle, θ, can be found from the expression

$$\theta = \Delta\lambda\ell$$

$\Delta\lambda$ is the change in longitude from the central meridian, and ℓ is a constant for the zone. The central meridian for Colorado is $105^\circ 30' 00''$, and the constant ℓ is 0.6306895773.

$$
\begin{aligned}
\theta &= \Delta\lambda\ell \\
&= (105^\circ 30' 00''.0 - 104^\circ 59' 03''.6)(0.6306895773) \\
&= (00^\circ 30' 56''.4)(0.6306895773) \\
&= 00^\circ 19' 30''.8
\end{aligned}
$$

The second-term, or θ', value is $-01''.8$, as derived in Sol. 64.7.

$$
\begin{aligned}
\theta' &= \left(\frac{x_2 - x_1}{2\rho_o^2 \sin 1''}\right)\left(y_1 - y_o + \frac{y_2 - y_1}{3}\right) \\
&= \left(\frac{21.115 \times 10^5 - 21.450 \times 10^5}{2\rho_o^2 \sin 1''}\right) \\
&\quad \times \left(\begin{array}{l} 6.945 \times 10^5 - 4.617 \times 10^5 \\ \quad + \dfrac{7.014 \times 10^5 - 6.945 \times 10^5}{3} \end{array}\right) \\
&= (-0.335 \times 10^5)(2.359 \times 10^{-10}) \\
&\quad \times \left(2.328 \times 10^5 + \frac{0.069 \times 10^5}{3}\right) \\
&= (-0.335 \times 10^5)(2.359 \times 10^{-10})(2.351 \times 10^5) \\
&= (-0.335 \times 10^5)(5.546 \times 10^{-5}) \\
&= -01''.8
\end{aligned}
$$

The formula for the geodetic azimuth of a long line when the grid azimuth is available is

$$
\begin{aligned}
\text{geodetic azimuth} &= \text{grid azimuth} + \theta - \theta' \\
&= 282^\circ 43' 26''.1 + (+00^\circ 19' 30''.8) \\
&\quad - (-00^\circ 00' 01''.8) \\
&= 283^\circ 02' 58''.7
\end{aligned}
$$

The answer is (D).

68. There is more than one method of finding the latitude of a station, given the state plane coordinates. One method is to calculate θ, and then find the value of R, the distance from the apex of the cone to the station. With this data, the latitude of the station can be derived from the given tabular values.

First, find x' from

$$
\begin{aligned}
x' &= x - C \\
&= 2{,}146{,}262.93 - 2{,}000{,}000 \\
&= 146{,}262.93
\end{aligned}
$$

Next, find θ from

$$
\begin{aligned}
\tan\theta &= \frac{x'}{R_b - y} \\
&= \frac{146{,}262.93}{26{,}243{,}052.74 - 742{,}549.22} \\
&= \frac{146{,}262.93}{25{,}500{,}503.52} \\
&= 0.005735688 \\
\theta &= +00^\circ 19' 43''.06
\end{aligned}
$$

Next, find the value of R from

$$
\begin{aligned}
R &= \frac{R_b - y}{\cos\theta} \\
&= \frac{26{,}243{,}052.74 \text{ ft} - 742{,}549.22 \text{ ft}}{\cos +00^\circ 19' 43''.06} \\
&= \frac{25{,}500{,}503.52 \text{ ft}}{0.999983551} \\
&= 25{,}500{,}922.98 \text{ ft}
\end{aligned}
$$

Find the corresponding value of ϕ by interpolating from the tabular information.

latitude	R (ft)	tabular difference for 1″ of latitude (ft)
39°51′	25,508,572.22	101.18867
52′	25,502,500.90	101.18933
?	25,500,922.98	calculated value of R
53′	25,496,429.54	101.19000

Find the difference in R from that of the next smaller latitude.

$$\begin{array}{r} 25{,}502{,}500.90 \text{ ft} \\ -25{,}500{,}922.98 \text{ ft} \\ \hline 1577.92 \text{ ft} \end{array}$$

Divide the difference by the corresponding tabular difference for 1 sec of latitude.

$$\frac{1577.92 \text{ ft}}{101.18933} = 15.''594$$

Finally, add the seconds to the next smaller latitude to find the latitude of the station.

$$\begin{array}{r} 39°52'00.''00 \\ \underline{00°00'15.''59} \\ \phi = 39°52'15.''59 \end{array}$$

The answer is (C).

69. When the mapping angle is given, the calculation of $\Delta\lambda$, or change in longitude, is fairly straightforward. The change in longitude can then be applied to the central meridian to find the longitude of the station.

Calculate $\Delta\lambda$ from

$$\begin{aligned} \Delta\lambda &= \frac{\theta}{\ell} \\ &= \frac{+00°19'43.''06}{0.6306895773} \\ &= +00°31'15.''820 \end{aligned}$$

Then apply the change in longitude to the central meridian.

$$\begin{aligned} \lambda &= \text{central meridian} - \Delta\lambda \\ &= 105°30'00.''00 - (+00°31'15.''820) \\ &= 104°58'44.''18 \end{aligned}$$

The answer is (D).

70. The sea-level factor will contribute the largest change to the measured distance. The traditional calculation of the factor uses the approximate radius of 20,906,000 ft for the reference spheroid.

$$\begin{aligned} \text{sea-level factor} &= \frac{20{,}906{,}000 \text{ ft}}{\begin{array}{c}\text{average elevation} \\ \text{of stations}\end{array} + 20{,}906{,}000 \text{ ft}} \\ &= \frac{20{,}906{,}000 \text{ ft}}{5343.5 \text{ ft} + 20{,}906{,}000 \text{ ft}} \\ &= \frac{20{,}906{,}000.00 \text{ ft}}{20{,}911{,}343.50 \text{ ft}} \\ &= 0.99974447 \end{aligned}$$

The scale factor is calculated for the stations at each end of the line and an average of the two taken. The scale factor is based on the latitude in the Lambert projection and found by interpolation.

The scale factor for Thornton 2 is

39°51′	25,508,572.22	101.18867	1.0000213
52′	25,502,500.90	101.18933	1.0000252
39°52′15.″594		....	?
53′	25,496,429.54	101.19000	1.0000291

First, find the difference in scale factor for a full minute of latitude from 39°52′ to 39°53′.

$$\begin{array}{lr} 39°53' & 1.0000291 \\ 39°52' & \underline{-1.0000252} \\ & 0.0000039 \end{array}$$

Next, find the proportional change in the scale factor for 15.″594 over the same interval.

$$\begin{aligned} \frac{x}{15.''594} &= \frac{0.0000039}{60''} \\ 60''x &= (0.0000039)(15.''594) \\ x &= \frac{0.00006082}{60''} \\ &= 0.0000010 \end{aligned}$$

This is the increase appropriate to the scale factor over 15.″594.

39°51′	25,508,572.22	101.18867	1.0000213
52′	25,502,500.90	101.18933	1.0000252
39°52′15.″594		....	1.0000262
53′	25,496,429.54	101.19000	1.0000291

Repeating the same process for point 400 yields a scale factor for that point of 1.0000210.

The average of the two scale factors at each end of the line is the scale factor for the line.

$$\frac{1.0000262 + 1.0000210}{2} = 1.0000236$$

The scale factor for the line is 1.0000236, and the sea-level factor is 0.99974447. The product of these two factors is the grid, or combination, factor for the line.

$$\begin{aligned} \text{grid factor} &= (\text{sea-level factor})(\text{scale factor}) \\ &= (0.99974447)(1.0000236) = 0.99976806 \end{aligned}$$

The product of the measured distance, 10,206.50 ft, and the grid factor, 0.99976806, is the grid distance.

$$(10{,}206.50 \text{ ft})(0.99976806) = 10{,}204.13 \text{ ft}$$

The answer is (B).

GOVERNMENT ADMINISTRATION OF STATE PLANE COORDINATE SYSTEMS

71. The original request for a state plane coordinate system was submitted to the U.S. Coast and Geodetic Survey by an engineer from a state highway department in 1933. Within a year of the establishment of the North Carolina Coordinate System, a similar system had been designed for every state by Dr. O. S. Adams, a mathematician in the division of geodesy of the U.S. Coast and Geodetic Survey.

The answer is (B).

72. The individual state legislatures have jurisdiction over the legal status of the use of state plane coordinate systems.

The answer is (D).

73. Every state and possession of the U.S. has had a state plane coordinate system designed for it.

The answer is (A).

74. Formerly known as the U.S. Coast and Geodetic Survey, the National Geodetic Survey maintains and publishes the coordinates of geodetic control stations across the U.S.

The answer is (D).

STANDARDS

75. In *Geometric Geodetic Accuracy Standards and Specifications for the Use of GPS Relative Positioning Techniques*, the previously established first-order, second-order classes one and two, and third-order classifications are all found under order C.

The answer is (D).

76. The data submitted to the National Geodetic Survey for blue booking must meet several requirements. For example, it must be properly formatted as described by the Federal Geodetic Control Subcommittee (FGCS) and it must meet accuracy standards. GPS and conventional horizontal surveys must meet first-order horizontal accuracy standards. Conventional geodetic leveling must meet second-order, class II vertical accuracy standards. Gravity surveys must meet third-order gravity accuracy standards.

The answer is (D).

77. Order A requires that three or more independently determined baselines from three or more observing sessions be included in the loop closure analysis. Loop closures incorporating only baselines determined from common observing sessions are not valid for analyzing the internal consistency of the GPS survey network.

The answer is (B).

78. The data quality group is comprised of these modules: logical consistency, lineage, attribute accuracy, positional accuracy, and completeness. A data dictionary module is not among them.

The answer is (D).

79. The Federal Geodetic Control Committee was chartered on Dec. 11, 1968, and is responsible for coordinating the geodetic surveying activities of federal agencies. The organization publishes standards of geodetic surveying by various methods, including provisional standards for GPS surveying.

The answer is (C).