

Datum Shifts for UTM Coordinates

R. Welch and A. Homsey

Abstract

The USGS 1:24,000-scale topographic maps and associated digital map products of the United States are cast on the North American Datum of 1927 (NAD 27). These map products are a national asset used for a variety of mapping, GIS database construction, and land survey tasks. However, NAD 27 has been replaced by the North American Datum of 1983 (NAD 83). While shifts to translate the latitude/longitude (lat/long) graticule coordinates to NAD 83 are documented, no information is readily available on the shifts in metres needed to convert NAD 27 UTM Northing and Easting grid coordinates to NAD 83 values. These shifts may be determined with computer software such as the U.S. Army Topographic Engineering Center (TEC) CORPSCON package or the commercially available Blue Marble Geographics Geographic Calculator program, and, when plotted at 2° intervals (lat/long) for the contiguous 48 states, show a remarkable consistency within the 6-degree-wide UTM zones, changing gradually from south to north. The shifts depicted in the graphical plots provide the map user with the values needed to quickly convert NAD 27 UTM grid coordinates to NAD 83 values. Because rectangular grid coordinates are preferred for a majority of tasks, it is recommended that the national mapping agencies determine the shift values to convert the NAD 27 UTM coordinates of individual map sheet corners to the datum of choice and make them available through publications and the World Wide Web. When map products are revised, notes defining shifts in rectangular grid coordinates should be included on the map collars or appended to the digital files.

Introduction

In the United States, the North American Datum of 1983 (NAD 83) is the current datum to which horizontal coordinates are being referenced for mapping and geographic information system (GIS) database construction applications (Schwarz, 1989). The NAD 83 replaces the North American Datum of 1927 (NAD 27) and closely corresponds to the World Geodetic System of 1984 (WGS 84) datum, the standard reference datum for the Global Positioning System (GPS) (Defense Mapping Agency, 1991) (Table 1). Because the NAD 27 is based on the Clarke 1866 ellipsoid, as compared to the Geodetic Reference System of 1980 (GRS 80) or World Geodetic System of 1984 (WGS 84) ellipsoids employed for the NAD 83 and WGS 84 datums, the horizontal coordinates for a given ground feature will differ significantly from those referenced to the more recent datums. That is, a translational shift must be applied to convert coordinates from one datum to another. This situation is further complicated because the horizontal shifts are different for *graticule* and *grid* coordinates. The *graticule* is defined in terms of latitude and longitude, specified in degrees, minutes, and seconds, whereas Universal Transverse Mercator (UTM) rectangular grid coordinates are given in metres (Snyder, 1987).

The U.S. Geological Survey's (USGS) 1:24,000-scale 7 1/2-

TABLE 1. DATUMS AND REFERENCE ELLIPSOIDS.

Datum	Reference Ellipsoid	Semi-Major Axis (a) in Metres	Shape (1/f)
NAD 27	Clarke 1866	6378206.4	1/294.9786982
NAD 83	GRS 80	6378137	1/298.257222101
WGS 84	WGS 84	6378137	1/298.257223563

minute topographic map sheets, Digital Line Graph (DLG) products, and Digital Elevation Models (DEMs) of the United States are cast on the North American Datum of 1927 (NAD 27). Only the new USGS Digital Orthophoto Quarter Quads (DOQQ) are cast on NAD 83. Because the USGS map sheets and digital data sets are being employed for many GIS database applications referenced to NAD 83, it is important that the user be able to achieve registration between the data layers derived from these and other map products to accuracies commensurate with U.S. National Map Accuracy Standards (NMAS). This means that all horizontal coordinates must be referenced to a single datum (Welch, 1995) (Figures 1a and 1b).

In order to facilitate use of the USGS map and DLG products in establishing planimetric feature locations referenced to NAD 83, the shifts in UTM *grid* coordinates between NAD 27 and NAD 83 must be determined and applied as appropriate. The need to apply shifts is not fully understood by the majority of map users and the problem has been only partially addressed by the USGS. At this time, the *North American Datum of 1983 Map Data Conversion Tables* (USGS, 1989), a three-volume set of books available from the USGS, provide the NAD 27 to NAD 83 shifts in metres for the lower, left-hand corner *graticule* coordinates (i.e., latitude and longitude) of the 7 1/2-minute map sheets. These tables and the North American Datum Conversion (NADCON) software available from the National Geodetic Survey (NGS) are referenced on the collar of USGS maps as a source for determining shifts in the *graticule*. However, neither the tables nor the NADCON software provides shifts for *grid* coordinates. This is only readily accomplished by using recent software packages such as the U.S. Army Corps of Engineers CORPSCON program, the commercially available Blue Marble Geographic Calculator package, or software from the vendors of GPS receivers and GIS software. The user will note that the shifts for the *graticule* are on the order of tens of metres, whereas the corresponding shifts for the UTM *grid* coordinates range from approximately zero to 400 m, depending upon the map location and UTM zone. An additional problem for surveyors and map users is that the CD-ROMs available from the NGS listing geodetic control provide NAD 83 UTM coordinates for horizontal control points but not NAD 27 UTM coordinates. Thus,

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Center for Remote Sensing and Mapping Science, Department of Geography, The University of Georgia, Athens, GA 30602.

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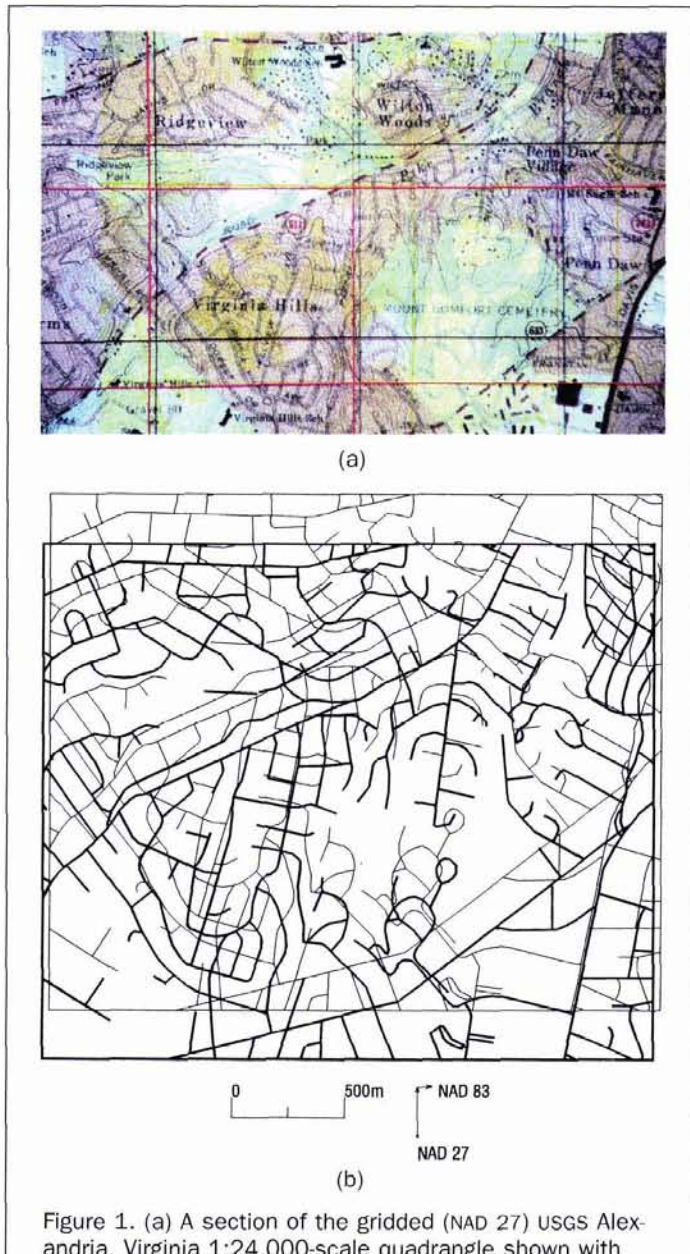


Figure 1. (a) A section of the gridded (NAD 27) USGS Alexandria, Virginia 1:24,000-scale quadrangle shown with the NAD 83 UTM grid superimposed in red. (b) Features on the Alexandria quadrangle plotted in both NAD 27 (heavy line) and NAD 83 (fine line) UTM coordinates indicate the problem of registering data sets referenced to different datums, and demonstrate the need to convert all data sets to a single horizontal datum — either NAD 27 or NAD 83.

in the absence of information on the NAD 27 to NAD 83 shift for UTM grid coordinates, it is difficult to accurately determine the location of these control points on the USGS topographic quadrangles. The objective of this paper is to define approaches to determining the shifts in UTM grid coordinates for NAD 27 to NAD 83 and vice versa.

Software for Determining Coordinate Shifts

The problem of converting between NAD 27 and NAD 83 can be addressed through the use of third-party software packages available for personal computers (PCs) and workstations.

Use of this type of software normally involves digitizing points from a map or orthophoto, placing them in an appropriate format, and then transforming them, either interactively or in batch mode, to the desired datum.

The parent program for most datum conversion software is NADCON, a DOS-based public domain software package produced by the NGS (Dewhurst, 1990). It provides a simple, accurate, and readily available way to transform graticule (geographic) coordinates from NAD 27 to NAD 83 (or vice versa). The NADCON software interpolates shifts across North America (including Alaska, Hawaii, the Virgin Islands, and Puerto Rico) based on the coordinates of selected reference stations. When the user supplies the latitude and longitude of a point in one datum (NAD 27 or NAD 83), the latitude and longitude in the other datum are returned to accuracies of better than ± 0.5 m at the one-sigma level. The newer versions of NADCON also include the option of converting to/from NAD 83 using High Accuracy Reference Network (HARN) data, where available (Doyle, 1993).

The NADCON software is run from the DOS prompt and has a "linear" interface in which the user is prompted for input at each step. There is no provision to correct a mistake entered in earlier steps. While it is possible to interactively enter the lat/long coordinates of points to be converted, most users will find it easier to process coordinate data in batch mode. Three formats are supported for batch input — standard NGS "Blue Book" format and two "free-form" ASCII formats. Output options include typing to the screen, to a text or NGS Blue Book file, or to a printer. In addition to the transformed geographic coordinates, output includes the shift values Δ latitude and Δ longitude in metres. The user must understand that this shift in metres derived from NADCON applies only to the graticule, not to the grid.

While NADCON does provide a means of transforming geographic coordinates, most map users are interested in plane coordinates. As an answer to some of the drawbacks of NADCON, the US Army Topographic Engineering Center (TEC) produced CORPSCON, or CORPSCON, a DOS-based software package with a menu-driven (and hence more "user-friendly") interface (U.S. Army Topographic Engineering Center, 1992) (Figure 2). The CORPSCON software incorporates the NADCON program to make the conversions between datums in geographic coordinates, but also includes a conversion between geographic and UTM or State Plane Coordinate System (SPCS)

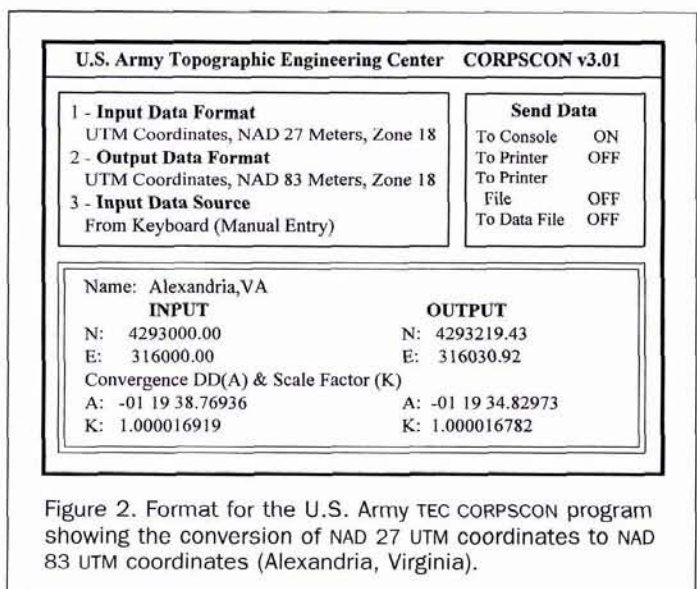
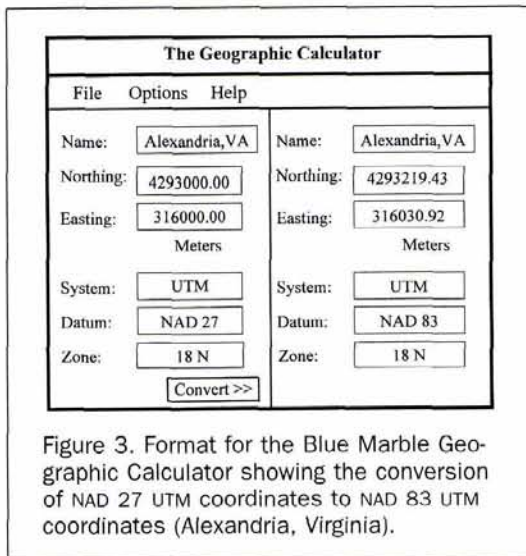


Figure 2. Format for the U.S. Army TEC CORPSCON program showing the conversion of NAD 27 UTM coordinates to NAD 83 UTM coordinates (Alexandria, Virginia).



coordinates. The user may enter coordinates interactively or in batch mode, and send the output to the screen, a file, or the printer.

Despite its greater ease of use and the capability to convert grid coordinates, CORPSCON still presents the datum shift in metres for the graticule, not the grid coordinates. In order to determine the shift in grid coordinates, the user can subtract the NAD 27 grid coordinates from the computed NAD 83 values (or vice versa).

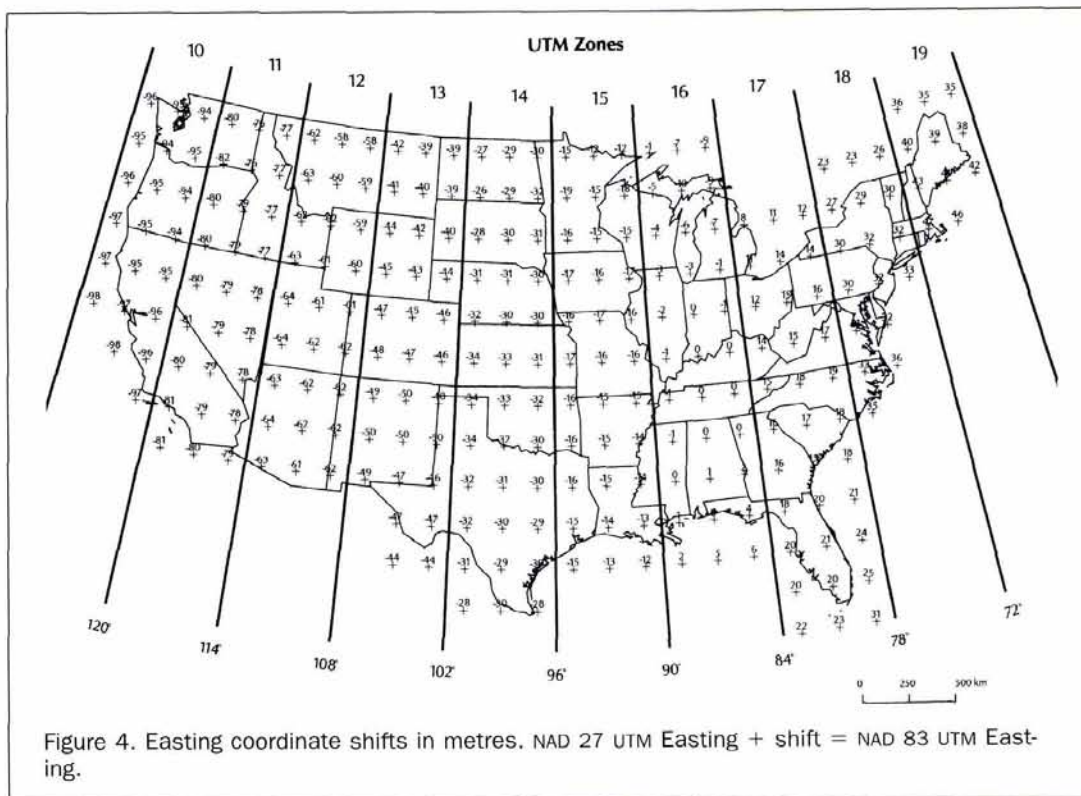
The Geographic Calculator, from Blue Marble Geographics, provides another tool for coordinate transformation (Blue Marble Geographics, 1994) (Figure 3). It is Windows-based, providing a user-friendly menu interface. As with the other

packages, coordinates may be entered interactively or in batch mode. The Geographic Calculator, however, provides much greater flexibility in the allowable types of input files. Supported formats include ASCII text, AutoCAD DXF, Arc/Info Generate, and NGS Blue Book. If desired, the user may also choose a datum transformation method (other than the NADCON method) that may be more suitable for areas outside North America. Overall, the Geographic Calculator provides a choice of many projections and datums not available through NADCON or CORPSCON, and greatly facilitates coordinate transformation. However, its proper use requires some basic knowledge of coordinate transformation issues as well as access to a computer.

UTM Coordinate Shifts — NAD 27 to NAD 83

The shifts in Easting values depicted in Figure 4 at 2° (lat/long) intervals, when added to the NAD 27 UTM Easting coordinates extracted from USGS map sheets, yield NAD 83 UTM Easting values. Because the UTM Northing coordinates have their origin at the equator and increase from zero toward the North pole, the different ellipsoids — Clarke 1866 for NAD 27 and GRS 80 for NAD 83 — will produce a shift in Northing coordinates between datums that gradually increases northward across the United States. Figure 5 illustrates that within the contiguous 48 states the magnitude of the shift varies from about 194 m in southern California to approximately 224 m in New England. Again, these shifts can be added to NAD 27 UTM Northing values to obtain the NAD 83 UTM Northing coordinates.

It is of interest to note that, for states or large regions contained completely within a given UTM zone, an average shift value can be approximated for each of the Easting and Northing coordinates and applied to digitized map coordinates without introducing significant error. For example, in Indiana the shift to convert NAD 27 UTM coordinates to NAD 83 UTM coordinates is approximately 0 m for Easting values and +214 m for Northing values. When referenced to the



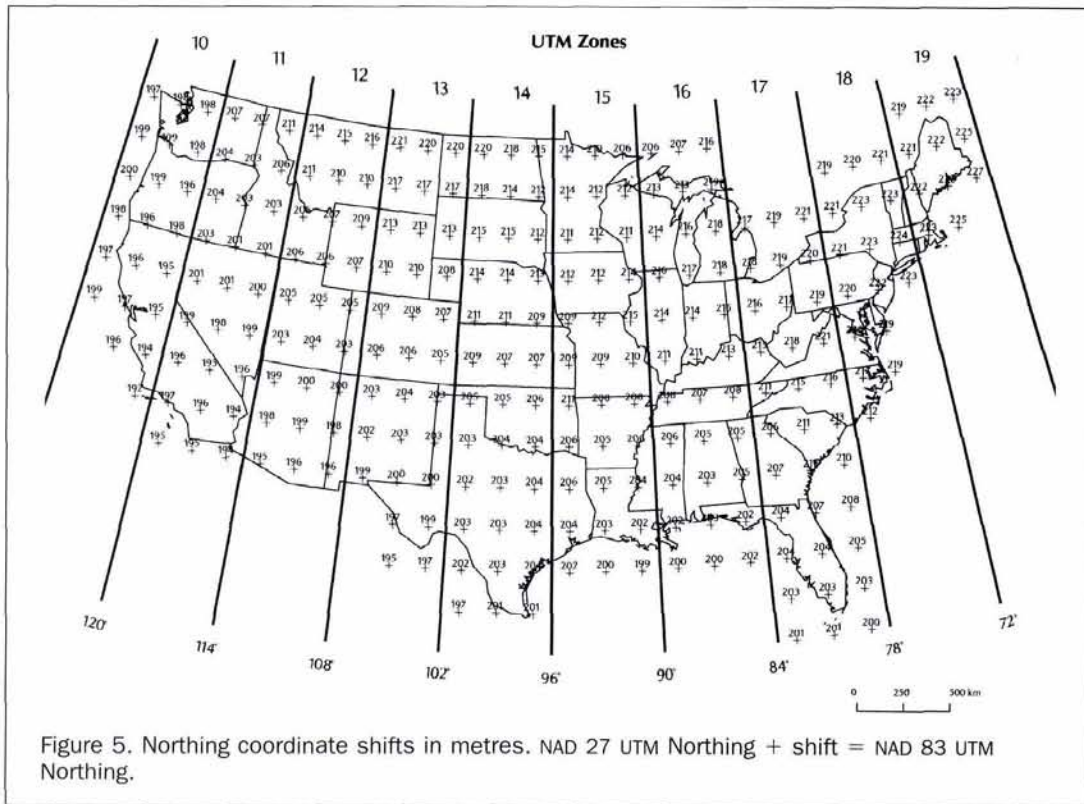


TABLE 2. POSSIBLE OUTPUT FORMAT SHOWING UTM COORDINATE SHIFTS (NAD 27 TO NAD 83) FOR USGS 1:24,000-SCALE MAP CORNERS.

		UTM Zone 16		Latitude 38° 45' 00" N			
		UTM (m)					
Longitude (W) NAD 27		NAD 27		NAD 83		Shift (m) NAD 27 to 83	
deg min sec		Easting	Northing	Easting	Northing	ΔE	ΔN
084	00 00	760719.61	4293101.50	760718.88	4293316.93	-0.74	215.43
084	07 30	749854.26	4292752.52	749853.57	4292967.85	-0.70	215.33
084	15 00	738989.17	4292418.42	738988.52	4292633.65	-0.65	215.24
084	22 30	728124.33	4292099.19	728123.77	4292314.32	-0.56	215.12
084	30 00	717259.72	4291794.85	717259.26	4292009.86	-0.46	215.01
084	37 30	706395.34	4291505.37	706394.82	4291720.22	-0.52	214.85
084	45 00	695531.17	4291230.76	695530.59	4291445.44	-0.58	214.68
084	52 30	684667.21	4290971.02	684666.86	4291185.57	-0.35	214.55

USGS 1:24,000-scale map series, differences between such averaged values and the true shift values are relatively insignificant for many applications because the 1:24,000-scale maps (which do meet NMAS) generally will only allow the digitizing of features to accuracies of approximately ± 5 to ± 10 m. Thus, Figures 4 and 5 provide a useful summary of shift values that can be employed to convert map-derived UTM coordinates from NAD 27 to NAD 83 (or vice versa). They also demonstrate the uniformity of the UTM coordinate system over a 6-degree (longitude) wide UTM zone.

It also would be relatively easy to create a publication similar to the USGS tables that lists the exact shifts in UTM grid coordinates for individual 7½-minute map sheets, and to provide access through the World Wide Web (Table 2). Of course, in the longer term, the USGS could modify the marginal notes to indicate the shifts necessary to transform 1:24,000-scale map sheets (or digital data sets) referenced to the appropriate datum.

Conclusion

The 1:24,000-scale topographic maps of the United States and associated digital map products, cast on the NAD 27, are

source material for a range of mapping and database construction applications. They are a national asset. In order to extend their lifetime and facilitate their use in the context of NAD 83 or future revised datums, an effort should be made to provide the map user with a ready reference for the shift values required to convert NAD 27 graticule and grid coordinates to the datum of choice. This can be accomplished if mapping agencies (such as the USGS) publish shift values for individual map sheets and make this information available through printed documents and/or the World Wide Web. In the longer term, it would be appropriate to include shift values in the marginal notes of maps and digital data sets.

Acknowledgments

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While you're at the 1997 ASPRS Annual Convention in Seattle, enjoy these events!

ASPRS Welcoming Convention Kick-off

Monday, April 7, 1997

10:15-11:00am, CC 602-603

The full slate of activities of the 1997 ACSM/ASPRS Annual Convention and Expo may overwhelm and bewilder you. ASPRS cordially invites all members and non-members registering for the first time for an ASPRS/ACSM Annual Meeting to attend this ASPRS welcoming social. Meet the Officers, Region and Division Directors of the Society. Obtain helpful hints on how to make the most of your time during the convention to get the maximum value out of the experience, and the greatest return on your investment. A complimentary continental breakfast will be served.

ASPRS Memorial Address & Awards Reception

Tuesday, April 8, 1997

5:00-6:30pm

All are welcome.

Memorial Addresses

Knowledge of the historical development of photogrammetry, remote sensing and other mapping science technologies is important to understand fully the scope and significance of those sciences in the current milieu.

George F. Walker was an innovative pioneer in the application of photogrammetry to surveying and engineering projects throughout the Pacific Northwest. After serving as a Marine in World War II, he received a BS in Forestry from the University of Washington and an MS in Photogrammetry from Syracuse University. He spent a brief period with USGS as a stereo-compiler and then moved to Seattle where he became an outstanding private practitioner in photogrammetry, always on the leading edge adopting of new methods.

Victor L. Bellerue had a distinguished career in private practice photogrammetry that continued for more than 42 years. After completing his education at Pasadena City College, the University of Wisconsin and the University of

Southern California, he held key positions at Fairchild Aerial Surveys; Daniel, Mann, Johnson and Mendenhall; Raytheon Autometrics; and Aero Service Corporation. He was a longtime active member of ASPRS and eventually became an Emeritus Member.

Awards Presentations

Share in the recognition of outstanding students and join in congratulating current members for their special achievements and service to the Society. Awards to be presented include student scholarships and fellowships, the International Educational Literature Award, Region of the Year Award, Region Newsletter of the Year Award, and Certificates of Appreciation for Meritorious Service. An open reception immediately follows. All convention attendees are invited.

ASPRS 8th Annual Awards Luncheon & 63rd Annual Installation of Officers

Wednesday, April 9, 1997

11:45am-2:00pm

\$18 per person

Join in recognizing your colleagues Society's vision of the future in an atmosphere of celebration, good food, and warm company. The awards portion of the program will feature presentations of awards for outstanding papers, professional achievement, and service. The business meeting will include the installation of Officers and Directors, remarks by retiring President Tina Cary, inaugural address by incoming President Roger Crystal, and the Executive Director's report. Stop by the Registration desk to order your tickets.

Open ASPRS Board Meeting

Thursday, April 10, 1997

8:00am-5:00pm

All members of ASPRS are invited and encouraged to attend the ASPRS Board of Directors meeting on Thursday, April 10. Hear first-hand reports of the Divisions, Regions and Committees as well as discussions on a host of issues, including membership, publications, meetings and finances. Witness the governance of your Society in action. Occasionally, items may be discussed in Executive Session.