```
....
0.215 9.297
0.166 9.319
0.050 9.340
0.055 9.324
0.006 9.324
-0.022 9.308
-0.105 9.286
-0.243 9.281
-0.530 9.270
-0.640 9.276
....
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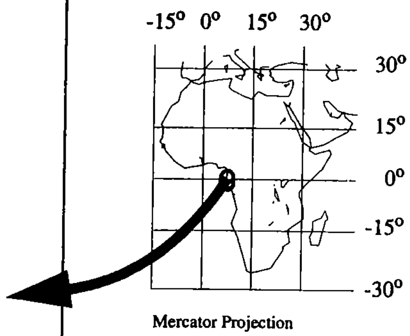

Figure 2.10 Part of the World Data Bank I listing of the coordinates of the coastline of Africa. Format is geographic coordinates in decimal degrees.

The advantage of using geographic coordinates in a GIS is that all maps can be transformed into a projection in the same way. If maps captured on a variety of projections are reprojected into geographic coordinates, there is some room for error. For example, the points in Figure 2.10 can never achieve a resolution better than 111 meters, regardless of the projection. If, however, the GIS does not support transformations between projections, then working in a common coordinate system such as the UTM or state plane system is very important if the maps are expected to overlay each other.

2.3.2 The Universal Transverse Mercator Coordinate System

The universal transverse Mercator (UTM) coordinate system is commonly used in GIS because it has been included since the late 1950s on most USGS topographic maps. The choice of the transverse Mercator, probably now used more than any other projection for accurate mapping, has an interesting history. The story begins with the observation that the equatorial Mercator projection, which distorts areas so much at the poles, nevertheless produces minimal distortion laterally along the equator.

Johann Heinrich Lambert modified the Mercator projection into its transverse form in 1772, in which the "equator" instead runs north-south. The effect is to minimize distortion in a narrow strip running from pole to pole. Gauss further analyzed the projection in 1822, and Kruger worked out the ellipsoid formulas in 1912 and 1919 adjusting for "polar flattening." As a result, the projection is often called the Gauss conformal or the Gauss–Kruger, although the name *transverse Mercator* is used in the United States. Rarely, however, was the projection used at all until the major national mapping efforts of the post–World War II era.

The transverse Mercator projection, in various forms, is part of each of the state plane, the civilian UTM system described here, and the military grid. It has been used for mapping most of the United States, many other countries, and even the planet Mars. The first version is the civilian UTM grid, used by the U. S. Geological Survey on its maps since 1977, marked on many maps since the 1940s as blue tic marks along the edges of the quadrangle maps or grids over the surface. In 1977 the transverse Mercator projection replaced the polyconic for large-scale U.S. mapping.

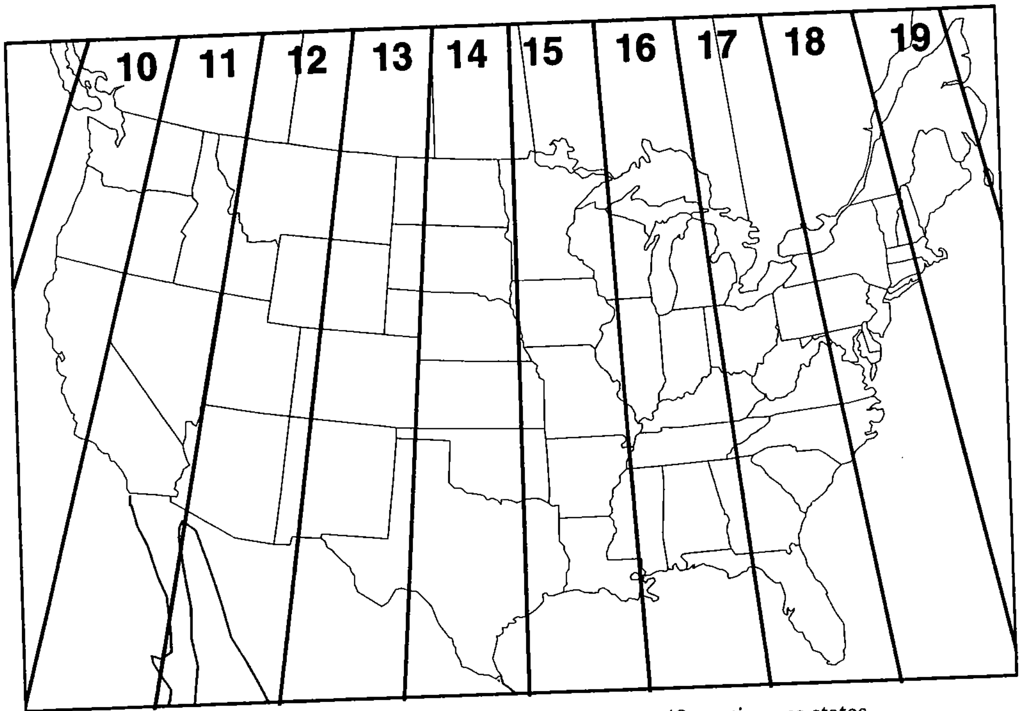

Figure 2.11 Universal transverse Mercator zones in the 48 contiguous states.

UTM capitalizes on the fact that the transverse Mercator is accurate in north-south strips by dividing the earth up into pole-to-pole zones, each 6 degrees of longitude wide, running from pole to pole. The first zone starts at 180 degrees west (or east), at the international date line, and runs east, that is, from 180 degrees west to 174 degrees west. The final zone, zone 60, starts at 174 degrees east and extends east to the date line. The zones therefore increase in number from west to east. For the coterminous United States, California falls into zones 10 and 11, while Maine falls into zone 19 (Figure 2.11).

Within each zone we draw a transverse Mercator projection centered on the middle of the zone oriented north-south. Thus for zone 1, with longitudes ranging from 180 degrees west to 174 degrees west, the central meridian for the transverse Mercator projection is 177 degrees west. Because the equator meets the central meridian of the system at right angles, we use this point to orient the grid system (Figure 2.12). In reality, the central meridian is set to a map scale of slightly less than 1, making the projection for each zone secant along two lines at true scale parallel to the central meridian.

To establish a coordinate system origin for the zone, we work separately for the two hemispheres. For the southern hemisphere, the zero northing is the South Pole, and we give northings in meters north of this reference point. As the earth is about 40 million meters around, this means that northings in a zone go from zero to 10 million meters.

The numbering of northings starts again at the equator, which is either 10 million meters north in southern hemisphere coordinates or 0 meters north in northern hemisphere coordinates. Northings then increase to 10 million at the north pole. As we approach the poles, the distortions of the latitude-longitude grid drift farther and farther from the UTM grid. It is customary, therefore, not to use UTM beyond 84 degrees north and 80 degrees south. For the polar regions, the universal polar stereographic coordinate system is used.

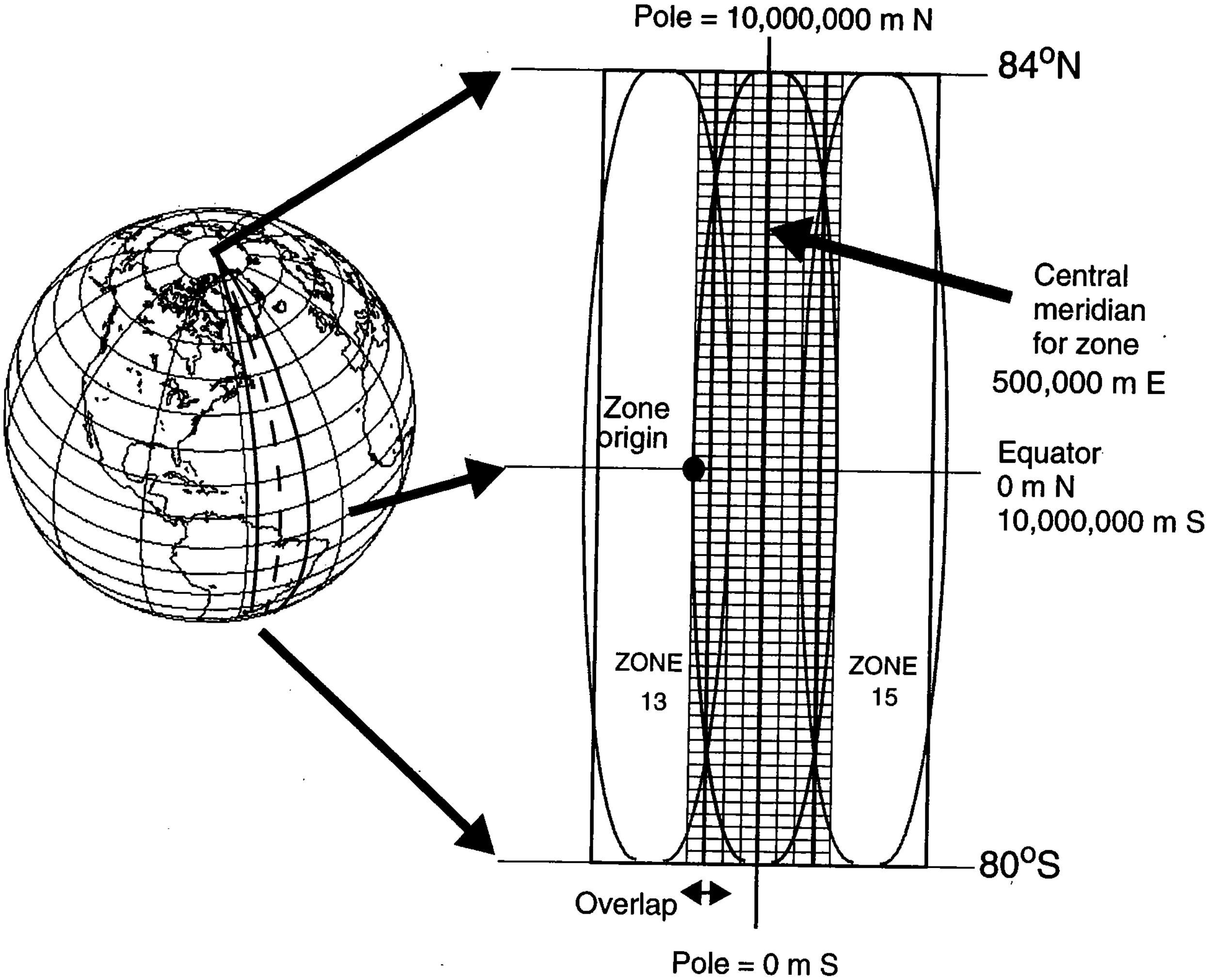

Figure 2.12 The universal transverse Mercator coordinate system.

For eastings, a false origin is established beyond the westerly limit of each zone. The actual distance is about half a degree, but the numbering is chosen so that the central meridian has an easting of 500,000 meters. This has the dual advantage of allowing overlap between zones for mapping purposes and of giving all eastings positive numbers. We can tell from our easting if we are east or west of the central meridian, and so the relationship between true north and grid north at any point is known. To give a specific example, Hunter College in New York City is located at UTM coordinate 4,513,410 meters north; 587,310 meters east; zone 18, northern hemisphere. This tells us that we are about four-tenths of the way up from the equator to the north pole, and are east of the central meridian for our zone, which is centered on 75 degrees west of Greenwich. On a map showing Hunter College, UTM grid north would therefore appear to be east of true north.

The variation from true scale is 1 part in 1000 at the equator. As a Mercator projection, of course, the system is conformal and preserves the shape of features such as coastlines and rivers. Another advantage is that the level of precision can be adapted to the application. For many purposes, especially at small scales, the last UTM digit can be dropped, decreasing the resolution to 10 meters. This strategy is often used at scales of

1:250,000 and smaller. Similarly, submeter resolution can be added simply by using decimals in the eastings and northings. In practice, few applications except for precision surveying and geodesy need precision of less than 1 meter, although it is often used to prevent computer rounding error and is stored in the GIS nevertheless.

2.3.3 The Military Grid Coordinate System

The second form of the UTM coordinate system is the *military grid*, adopted for use by the U.S. Army in 1947 and used by many other countries and organizations. The military grid uses a lettering system to reduce the number of digits needed to isolate a location. Zones are numbered as before, from 1 to 60 west to east. Within zones, however, 8-degree strips of latitude are lettered from C (80 to 72 degrees south) to X (72 to 84 degrees north: an extended-width strip).

The letter designations A, B, Y, and Z are reserved for Universal Polar Stereographic designations on the poles. A single rectangle, 6 by 8 degrees, generally falls within about a 1000-kilometer square on the ground. These squares are referenced by numbers and letters; for example, Hunter College falls into grid cell 18T (Figure 2.13).

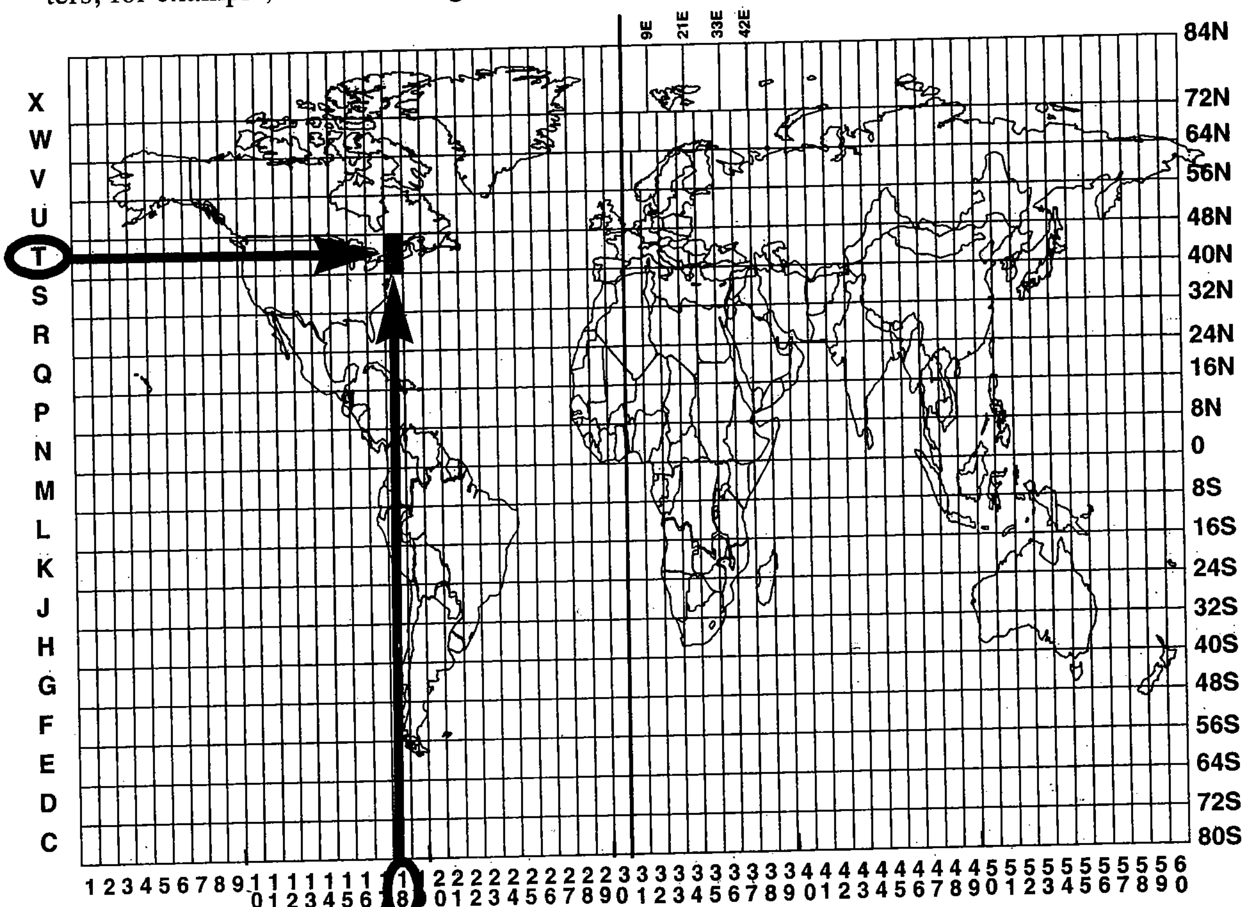

Figure 2.13 Six by eight-degree cells on the UTM military grid.

Each grid cell is then further subdivided into squares 100,000 meters on a side. Each cell is assigned two additional letter identifiers (Figure 2.14). In the east-west (x) direction, the 100,000-meter squares are lettered starting with A, up to Z, and then repeating around the world, with the exception that the letters I and O are excluded, because they could be confused with numbers. The first column, A, is 100,000 meters wide and starts at 180 degrees west. The alphabet recycles about every 18 degrees and includes about six full-width columns per UTM zone. Several partial columns are given designations nevertheless, so that overlap is possible, and some disappear as the poles are approached.

In the north-south (y) direction, the letters A through V are used (again omitting I and O), starting at the equator and increasing north, and again cycling through the letters as needed. The reverse sequence, starting at V and cycling backward to A, then back to V, and so on, is used for the southern hemisphere. Thus a single 100,000-meter grid square can be isolated using a sequence such as 18TWC. Within this area, successively accurate locations can be given by more and more pairs of x and y digits. For example, 18TWC 81 isolates a 10,000-meter square, 18TWC 8713 a 1000 meter square, and 18TWC 873134 a 100-meter square. These numbers are frequently stored without the global cell designation, especially for small countries or limited areas of interest. Thus WC873134, two letters and six numbers, would give a location to within 100-meter ground accuracy. Finally, the polar areas are handled completely separately on a different (UPS) projection.

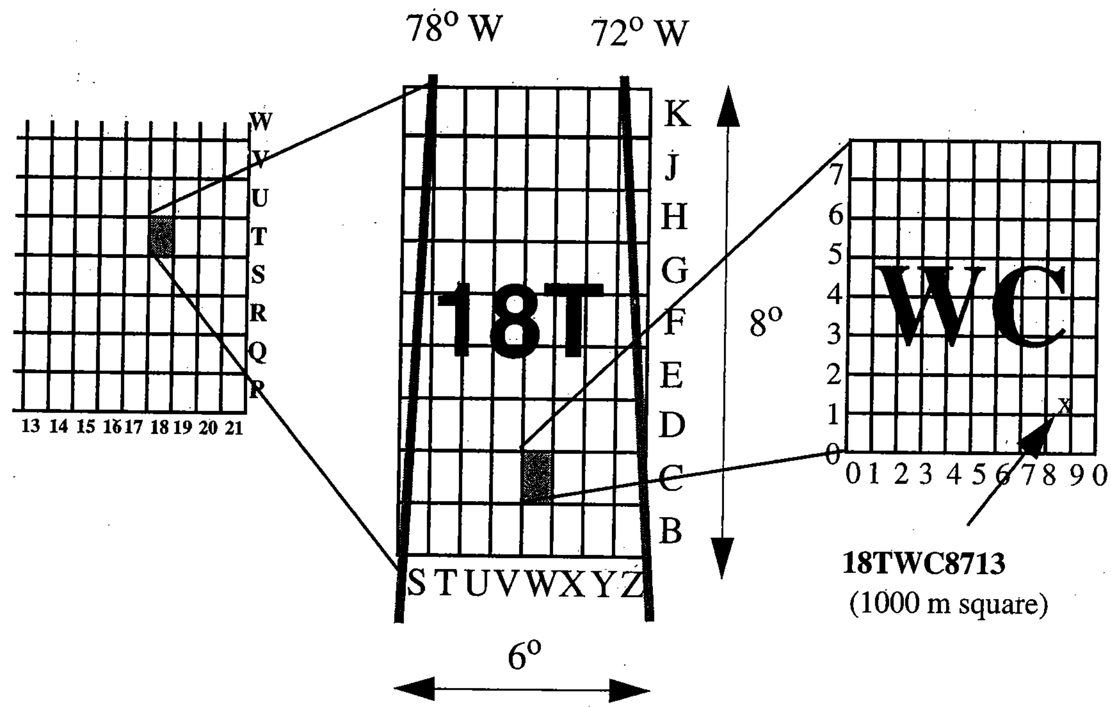

Figure 2.14 Military grid cell letters.

2.3.4 The State Plane Coordinate System

Much geographic information in the United States uses a system called the state plane coordinate system (SPCS). The system is used primarily for engineering applications, especially by utility companies and local governmnets that need to do accurate surveying of facilities networks such as power lines and sewers. The SPCS is based on both the transverse Mercator and the Lambert conformal conic projections with units in feet, although metric versions are now available. SPCS has been used for decades to write legal descriptions of properties and in engineering projects in many states. The SPCS is based upon a different map of each state, except Alaska. States that are elongated north to south, such as California, are drawn on a Lambert conformal conic projection. States that are elongated east to west, such as New York, are drawn on a transverse Mercator projection, because the zones are divided into north-south strips.

The state is then divided up into zones, the number of which varies from small states, such as Rhode Island with one to as many as five. Some zones have no apparent logic; for example, the state of California has one zone that consists of Los Angeles County alone. Some have more logic, so, for example, Long Island has its own zone for the state of New York. Because there are so many projections to cover the land area, generally the distortion attributable to the map projection is very small, much less than in UTM, where it can approach 1 part in 2000.

Each zone then has an arbitrarily determined origin that is usually some given number of feet west and south of the southwesternmost point on the map. This again means that the eastings and northings all come out as positive numbers. The system then simply gives eastings and northings in feet, often ending up with millions of feet, with no rounding up to miles. The system is slightly more precise than UTM because coordinates are to within a foot rather than a meter, and it can be more accurate over small areas. A disadvantage is the lack of universality. Imagine mapping an area covering the boundary between not only two zones, but two states. This means that you could be working with data that fall into four coordinate systems on two projections. Any calculation, such as computing an area, on that basis becomes a set of special case solutions. On the other hand, SPCS is used universally by surveyors all over the United States.

A sample set of zone information is shown in Figure 2.15. New York State is somewhat an exception. The bulk of the state, being east-west in extent, is divided into three north-south zones called "east," "central," and "west." Each of these three zones is drawn on a single Transverse Mercator projection with a central meridian at $74^\circ 30'$ West, with the scale factor at the center set at 0.9999, making the "cylinder" secant to the projection. Each zone then has an origin of zero feet set at the northing of the origin (40° N) and at the easting given in the table.

Coordinates in each zone are then numbered off in feet, and are given only as feet, not to another unit. New York has one zone, Long Island, that uses a Lambert conic projection. For this one zone, the origin is a point and the standard parallels are given. For example, a position could have the following state plane coordinates:

870, 432 feet North; 730, 012 feet East, New York, Central Zone.

New York State (3 zones on Transverse Mercator, 1 on Lambert Conic)
Based on NAD83

		Central Meridian	Origin	Scale reduction at Central Meridian	Easting at Origin
East	TM	74 30	40 00	1 in 10,000	150,000 m
Central	TM	74 30	40 00	1 in 10,000	250,000 m
West	TM	74 30	40 00	1 in 10,000	350,000 m
Long Island	LC	40 40 N 41 02 N	74 00W 40 10N		300,000 m

Figure 2.15 Statistics for New York State's state plane zones.

2.3.5 Other Systems

There are, in addition, many other coordinate systems. Some are standardized, but many are not. Most countries have their own, although many use UTM or the military grid. The national grid of the United Kingdom uses the lettering system of the military grid but different-sized zones. In a few cases, Sweden for example, the national census and other data are tied directly into the coordinates. Within the United States, many private companies and public services use unique systems, usually tied to specific functions such as power lines, or a specific region such as a municipality, or even a single construction project. There is also a tendency, especially when a base map is of unknown origin or when the map must be captured quickly, to throw away coordinates and just use "map millimeters" or "tablet coordinates." In this instance, unless we have the critical spatial fact of knowing at least two and preferably more points in both this and an accepted coordinate system, the map will be useless for matching with others or for overlay and analysis.

When using a coordinate system for geocoding in a GIS, we should be sure to remain consistent within that system and to record the relationship between the system and latitude and longitude or some other recognized system. Two points will suffice if the spatial extent is perfectly aligned and north is the same on both maps, but different projections and other differences make this a rare occurrence. Also, we should be sure to use precision and numbers that make sense. Can we really measure distances over entire states down to the micrometer level or below? And even if we can, is this efficient to use in the GIS? On the other hand, there is also a tendency to throw away precision needlessly.

Finally, while coordinates are the way that a GIS records information about location, location is just one of the many facets of geographic data. In the following section, we take a look at the full set of properties. Many of these become important to understand as we move into analysis and description of geographic features using a GIS.