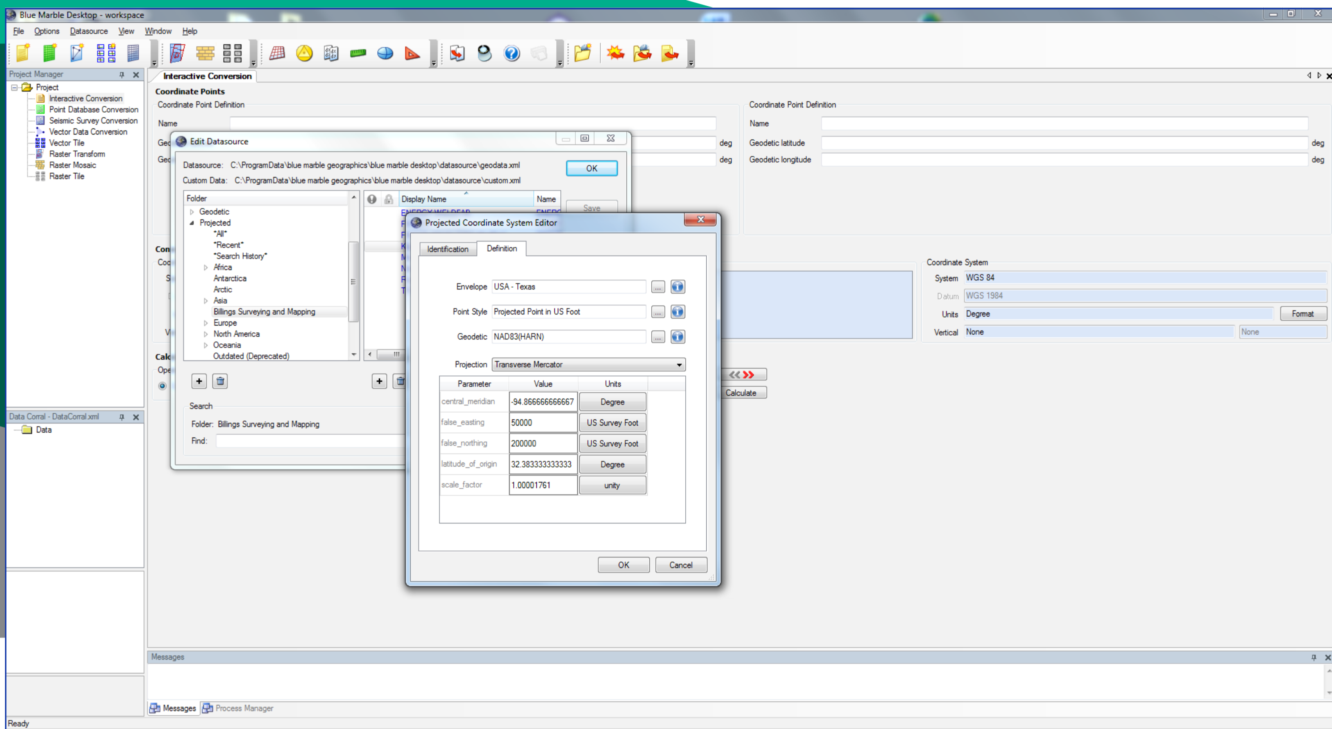


Blue Marble Geographic Calculator provides an incredible variety of tools for working with an infinite combination of datums and projections. Shown here, I've entered the parameters for a Low Distortion Projection for my home town. With these parameters established, I can transform numerous vector file types (such as .dwg, .dxf, and .dgn), numerous raster image file types (such as .sid, .jp2, .tif), or coordinate files to my new projection.

Low Distortion Projections—Part 2

GROUND VERSUS GRID

In Part 1, I highlighted the inherent deficiency of the State Plane Coordinate System with regard to excessive scale factors, the poor solutions often employed by surveyors and engineers to remedy that deficiency, and suggested a viable alternative through the use of Low Distortion Projections–LDP. I briefly outlined five surfaces of which surveyors should be aware (Ellipsoid, Topographic, Geoid, Design and Developed). Here, in Part 2, I will describe the actual design of two real world Low Distortion Projections and the benefit implementing your own LDPs could present in your own work.

The two developed surfaces we'll be discussing (Single Parallel Lambert–cone, and Transverse Mercator–cylinder) both require identical design input, namely: Latitude of Origin, Longitude of Origin, Northing of Origin, Easting of Origin, Scale Factor, Datum and Unit. By carefully selecting a Scale Factor based on our Design Surface ellipsoid height, we can minimize the combined factor of the points within our projection.

>> By Shawn Billings, PS

DESIGNING THE PROJECTION

In practice, I first look at project extent, with an eye toward future extension of the project. If I have a major highway nearby, I may select a projection type that follows the direction of the highway with a view toward doing more work someday along that highway, or if a county wide projection, I would look to see which direction the county predominantly extends. If the county, project or some nearby feature (such as a highway) runs predominantly East-West, I might elect to use a Lambert, or conversely, a Transverse Mercator if oriented more North-South. With that determined, I select a Datum, or ellipsoid, with which my projection will be based. I've always used NAD83, GRS80, as my ellipsoid. If the particular software I use does not distinguish between GRS80 and WGS84, I will use WGS84 as the differences for this application are negligible.

I then pick a central meridian (longitude of origin) and latitude of origin. This geodetic origin may be a theoretical point (such as the origin of an SPCS zone, a corner of a USGS Quadrangle Map, or the approximate center of a project, city or county), or this origin may be a specific physical location, such as a Public Land Survey System Township corner, a section corner, a US Mineral monument, the intersection of two prominent roads, the Point of Beginning of a Land Grant, or an existing survey control point. Much of our work is return visits to previous jobs. Because much of this work was based on an astronomic or geodetic bearing, I will put the geodetic origin through an existing point (such as the point used to determine the astronomic bearings originally). If I select a theoretical point, I generally use values rounded to the nearest minute to make documentation and entry simpler.

Next, together with this geodetic origin, we need grid coordinates assigned to that position. For this you will need to determine what units you want your projection to be based on: US Survey Foot, International Foot, Meter, Vara, Yard, Smoot, etc. With an eye toward the practical extents of the projection, assign a false Northing and Easting that will still allow a user to have coordinate values in the positive throughout the projection. Selecting values that are substantively different is also advised, making North and East distinguishable at a glance.

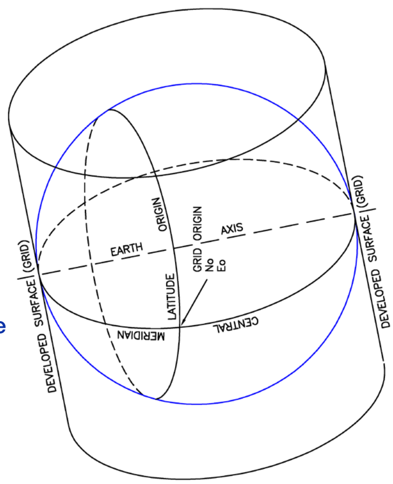
With a grid origin (Northing and Easting) now thumb tacked on the globe to a geodetic position (Latitude of Origin, Central Meridian), the only remaining criterion left to be designed is the scale factor. As previously described, the separation between the Ellipsoid and the Design Surface gives us an elevation factor. The distance between the Developed Surface (Grid) and the Ellipsoid give us a scale factor. Creating a scale factor that reciprocates the average elevation factor of our project area can produce a combined factor that approaches 1.

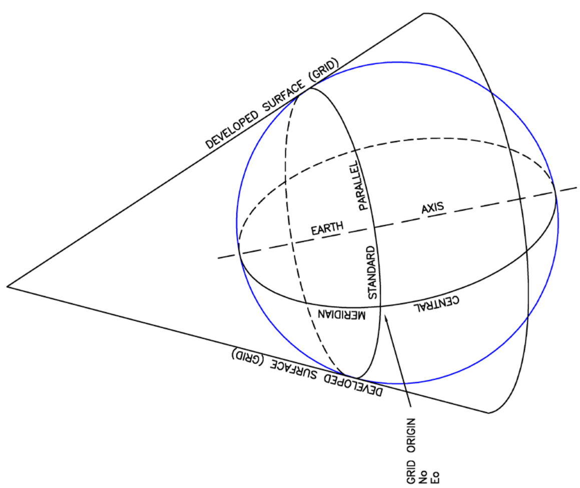
First we need to know the Elevation factor of our project relative to the Ellipsoid. A suitable approximation of the elevation factor can be had by dividing the mean Earth radius of 20,906,000 by the sum of average ellipsoid height of the projection and the mean Earth radius 20,906,000 (US Survey Feet):

Elevation Factor = 20,906,000/
[20,906,000 + Ellipsoid Height]

Remember, this is the ellipsoid height, not orthometric, therefore if you only have an orthometric height, use the NGS Geoid calculator available on the NGS website to determine the ellipsoid height. With the elevation factor determined, the scale factor for your new projection is simply the reciprocal of that elevation factor. Since the combined factor is the

Both the Single Parallel Lambert Projection (cone) and the Transverse Mercator Projection (cylinder) have the same user input: Standard Parallel/Latitude of Origin, Central Meridian, Northing of Origin and Easting of Origin. As can be visualized, the cone of the Single Parallel Lambert Projection follows the Standard Parallel around the globe (making it very suitable for East-West oriented projects) while the Transverse Mercator follows the Central Meridian around the globe (making it very suitable for North-South oriented projects).





product of the Elevation Factor and the Scale Factor:

Combined Factor = Elevation Factor x Scale Factor

then the resulting Combined Factor will approach 1 for all points within your projection, provided the elevations remain somewhat homogenous throughout the project.

So let's see what this looks like in practice.

In 1996, we surveyed a church property just up the road from our office. The property contained about 8 acres. The survey was primarily for topographic purposes for future expansion, but Dad rightly insisted we do a boundary survey as well. As was his practice then, he did solar observations on point no. 1, a 60d traverse nail. In 2006 we would return to perform more survey work to update as-built construction and extend our topographic work. We accomplished this by recovering some original traverse points, building corners, and boundary points located in the decade old survey. In 2008, the church was ready to begin construction of a much larger facility. The contractor wanted to use GPS guided machine control for the dirt work. For this, he required four points with which to localize/calibrate. We performed a static GPS survey of four new points in suitable locations and tied them to the HARN, and then made conventional ties to three or four existing points from our previous survey work and were then able to relate the old survey from 1996 to the State Plane Coordinate System of 1983 (Texas North Central Zone to be more particular).

Recently, we were tasked with extending our topographic survey yet again for a new building as well as locating some new structures constructed since our 2006 survey. Because of the limitations of SPC for design work and for conventional, terrestrial measurements, I didn't really want to work with SPC. Because the original '96 survey was done with Solar observations and those observations were verified to be highly accurate, I was able to develop a low distortion projection that maintained the same coordinates as the 1996 survey, used a negligible combined factor, and could do RTK surveying instantly, without any messy localizations, directly on our 1996 coordinate system.

I designed the Church Projection in just a few minutes using the procedure outlined above, and in more detail as follows (distances, coordinates and elevations are expressed in US Survey Feet):

Even though point no. 1 had not been recovered since 1996 (and may be lost for all I know), this was the origin of the '96 survey–N: 5000, E: 5000. I was able to determine the latitude and longitude of point 1 from the '08 GPS survey we did tying into '96 points.

> "Using LDPs allows me to determine positions with GNSS and get very agreeable measurements between those positions with my total station without any application of a combined factor.."

The latitude and longitude of point 1 (NAD83, HARN - 1993 Adjustment) was found to be 32°22'12.43295 N and 94°49'51.84116" W. The average elevation of the site is 380 AMSL (NAVD88). I chose to use a Transverse Mercator projection for simplicity. From the NGS Geoid12A calculator the Geoid separation for point 1 is -86.53. Ellipsoid height is reckoned by adding the Geoid separation to the Orthometric height):

Ellipsoid Height = Orthometric Height +Geoid Height

resulting in an ellipsoid height of 293.47 which we can shorten to 293 (with no significant impact on our design). Using the Elevation Factor formula:

Elevation Factor = 20,906,000/ [20,906,000 + Ellipsoid Height]

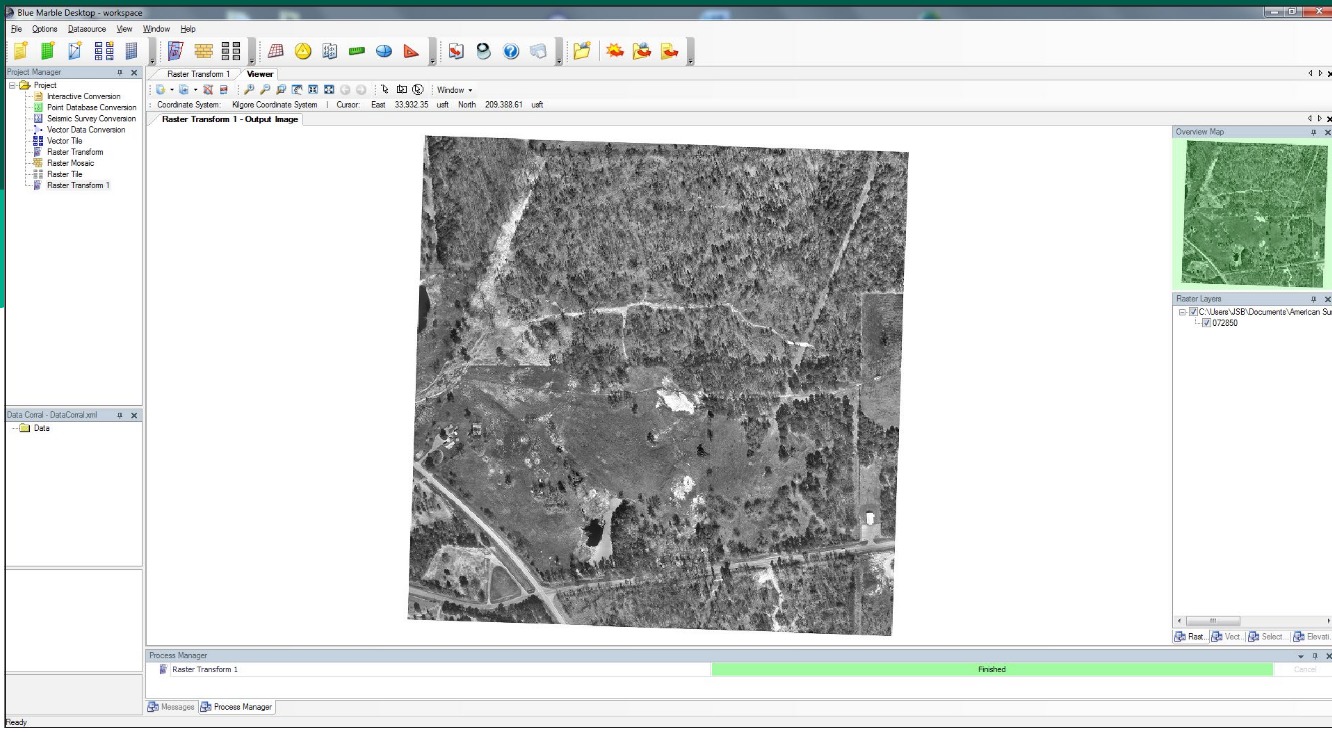
this results in an Elevation Factor of 0.9999 86, the reciprocal of which is 1.0000 14, which is also the Scale Factor I used for the projection.

Thus my projection setup looks as follows:

Datum	NAD83
Realization	Texas HARN (1993 Adjustment)
Latitude of Origin	32° 22' 12.43295" N
Central Meridian	94° 49' 51.84116" W
False Northing	5000
False Easting	5000
Scale Factor	1.000014
Projection Type	Transverse Mercator
Units	US Survey Foot

These parameters can be entered into a data collector, GNSS post-processing software, some least squares adjustment software, some CAD software, and coordinate transformation software such as the Blue Marble Geographic Calculator, to re-project coordinates, drawings and images from one system to another. With this projection set up in the data collector, I was able to begin RTK surveying immediately in coordinates that match those determined by terrestrial observations with imperceptible differences and without any of the slop associated with localizations/calibrations.

Having created a projection to accommodate an existing project, let's consider a build-from-scratch projection for the City of Kilgore. We perform services for the City and for the Economic Development Corporation from time to time, both boundary and for engineering design. The corporate limits of the City of Kilgore is relatively small and the variation in elevation is minimal, thus a single projection for the entire city is practical for maintaining negligible combined factors. Developing such a large projection to meet a plethora of here-to-fore unseen requirements necessitates a bit more consideration. First, we need to consider the overall vertical relief of the proposed projection area. The old USGS Quadrangle map remains a valuable asset in this. Looking at the major



Using Blue Marbe Geographic Calculator, I've reprojected a georeferenced, orthorectified aerial image from State Plane (Texas Coordinate System of 1983, North Central Zone, US Survey Feet, HARN) to the Kilgore Coordinate System (US Survey Feet, HARN). The original .tif image was over 25 MB in size, while the jpeg 2000 format I selected for output is only 1.27 MB and is ready for importing to CAD.

water sheds, what are the lowest elevations one is likely to encounter? What are the highest elevations? For Kilgore, this would be about 270 feet AMSL and 450 feet AMSL respectively (NAVD88). However, the most populous areas of town are in the range of 350-400 AMSL (NAVD88), thus a reasonable average orthometric elevation would be 375 feet. In this case averaging extreme elevation differences would give a similar result. That may not always be the case (imagine a lone hill in an otherwise flat area), so care should be taken to select an elevation that works over a majority of the projection area. Determining the Geoid Height (289') and using the same formulae given above, this resulted in an Elevation Factor of 0.9999 86, which would yield a designed Scale Factor of 1.0000 14, but I tweaked it after testing, as I'll explain in a moment.

In determining the geographic origin, I elected to use the approximate coordinates of a major intersection. US Highway 259 runs north to South and practically bisects the City of Kilgore, East from West, making a practical central meridian for the projection. Selecting round numbers for Latitude and Longitude for ease of documentation, I used 32°23' N for my Latitude of Origin and 94°52' W for my Central Meridian. Because the city extends slightly more North and South than East and West, I selected a Transverse Mercator Projection type.

Lastly, I assigned an Origin Northing and Origin Easting that would keep all future projects having positive coordinate values. I also made them an order of magnitude different to make Northing and Easting values easily distinguishable. I assigned a Northing of 200,000 and an Easting of 50,000 (US Feet) to my origin.

The City of Kilgore has 32 GPS monuments around town. These monuments were established by ties to the local area HARN monuments in 2000. Because of this I maintained the same Datum/Realization. I used these for my projection test. Once the projection was set up, I performed a batch re-projection of those points and found that the Combined Factors for almost all of them was less than one. All were very close to one as I had designed them to be, but with all

> "...there is no sacrifice of functionality, only an improvement in the marriage of the surveyor's total station and GNSS receiver..."

of them lopsided in one direction, I decided to modify the Scale Factor until there was a more even distribution of points with a roughly even number of points having a Combined Factor slightly less than one and slightly more than one. Ultimately this required a 4 parts-per-million adjustment to a Scale Factor of 1.0000 1761. In practice, this Scale Factor could be limited to only six decimal places, as the remaining mantissa is extraneous. My custom Low Distortion Projection for the City of Kilgore looked like this:

Datum	NAD83
Realization	Texas HARN (1993 Adjustment)
Latitude of Origin	32° 23' N
Central Meridian	94° 52' W
False Northing	200,000
False Easting	50,000
Scale Factor	1.00001761
Projection Type	Transverse Mercator
Units	US Survey Foot

Regarding error budgets–what combined factor is acceptable to ignore? Your project requirements (or lacking those, your personal standards) will dictate that. Throughout the city, the Combined Factor reaches a maximum of 5ppm. If ignored, a surveyor could traverse a mile and only accumulate a maximum of 0.026 foot of error due to scale factors. For our purposes this is negligible, particularly when compared to the 60ppm Combined Factor of the State Plane Grid around the city (Texas Coordinate System of 1983, North Central Zone). Once the projection is designed, a prudent surveyor will test extreme points in the project (along the edges and at extreme elevations) to determine if the LDP satisfies his requirements. While the labor involved in developing projections for larger areas like this will require more initial effort than those for small projects like the Church example above, every future project within the city (and nearby, outlying areas) can now be tied to the larger projection with no setup required. [Loyal adds a great tip regarding the design of a scale factor for your projection. By reducing the scale factor of your projection by one part-per-million (which is very negligible for most applications) the working limits of your projection (as governed by your error budget) can be extended by miles.]

These custom, Low Distortion Projections allow me to determine positions with GNSS (RTK or Static) and set up my total station on one of those positions, backsight another and get very agreeable measurements without using individual scale factors for each point, while at the same time allowing me to take my coordinates and reproject them instantaneously to any other projection (State Plane or otherwise) with only a few effortless clicks of a mouse using easily obtainable software, such as Blue Marble Geographic Calculator. I get all of the benefits of State Plane without the overhead of extreme combined scale factors and large mapping angles.

As Loyal has also revealed, maintaining Grid coordinate values can be much simpler with an LDP. It seems we were just getting cozy with NAD83(CORS96) when the NAD83_2011 was announced. The variation was relatively minor around here, about 0.05 foot horizontally. With a Low Distortion Projection in use, a surveyor could maintain his Grid coordinate database (Northings and Eastings) and make them compatible with future adjustments by simply adjusting the geodetic position of the origin by tiny amounts to accommodate any shift. Renaming the projection to include the year would help minimize confusion, and allow Latitude and Longitude coordinates from OPUS to be input at any time now or in the future while still being perfectly in agreement with previously established Grid coordinates from other adjustments.

In conclusion, Low Distortion Projections present a digital solution to a digital world. Where previous analog solutions, such as State Plane were incredibly sophisticated for the analog world in which they were conceived, the system has become an obstacle to be negotiated instead of a tool for productivity. Field equipment manufacturers have made GNSS and terrestrial based equipment very much plug and play. I can unplug my data collector from the robot and plug it into the RTK and keep working as if I haven't missed a beat. State Plane does not easily allow for this. Terrestrial equipment measures distances along the ground, while GNSS set to SPCS works on an invisible Grid that most likely is not coincident with the ground. Low Distortion Projections put that necessary invisible Grid closer to the ground so the practicing surveyor can continue working without any unnecessary application of large scale factors. Furthermore, using modern, easily accessible software, the practicing surveyor can toggle from one projection to another effortlessly, thus enabling him or her to provide point addresses to those clients who require them in SPC, UTM, Latitude and Longitude, or any other projection desired. This article only touches on the capabilities LDPs bring to practicing surveyors as there are numerous ways a LDP can be implemented to resolve connections to grid coordinates on the ground and geodetic positions relative to the Earth. In short, there is no sacrifice of functionality, only an improvement in the marriage of the surveyor's total station and GNSS receiver–and don't we love it when everyone gets along.

Shawn Billings is a licensed land surveyor in East Texas and works for Billings Surveying and Mapping Company, which was established in 1983 by his father, J. D. Billings. Together they perform surveys for boundary retracement, sewer and water infrastructure routes, and land development.