LOW-DISTORTION MAP PROJECTIONS

(LOCAL MAP PROJECTIONS)

Academic Perspective

Oregon GPS User's Group Meeting

4 November 2008

TECHNOLOGY REVOLUTION

Before the PC revolution, and the advent of GPS, and GIS technologies:

- Isn’t a “geoid” something you cut with a rock saw?
- Historically, Surveyors were licensed by “apprenticeship” with little formal education.
- “We don’t need a 4-year surveying program”

RESISTANCE TO TECHNOLOGY

- “The damned EDM ruined surveying!”
- “We don’t do that kind of work!” (GIS)
- “*#?*% State Plane coordinates don’t work!”

GEOMATICS DEPARTMENT

- Following the national trend, in July 2006, the Department of Civil Engineering and Geomatics became two separate departments:

- The Department of Civil Engineering

- The Department of Geomatics

GEOMATICS DEPARTMENT

- In 2007 the department began offering two degree options:
- Surveying Option (former Geomatics degree)
- GIS Option – This is a ‘hard science” degree requiring plane surveying, boundary law, geodesy, and map projection courses in addition to GIS course work. The emphasis is on land information applications.

GEOMATICS DEPARTMENT

- Enrollment increased 40% in 2007
- 2008 enrollment is almost 70 students
- Today's students find high technology "cool"
- Students are choosing Geomatics instead of engineering or computer science

GEOMATICS DEPARTMENT

Over $700,000 in equipment and software!

- 6 RTK GPS units
- 7 robotic total stations (ODOT donation!)
- 7 reflectorless total stations
- Complete ESRI GIS software suite
- ERDAS image processing & Leica analytical photogrammetry suite
- Hydrographic surveying equipment donation!

Practicum & Community Service Projects Include:

- BLM agreement for USPLSS retracement projects each year
- Partner with W&H Pacific and Epicscan on Lakeshore Dike project
- Collins Companies chip pile volume
- BOR wetland rebound monitoring

INDUSTRY PARTNERSHIPS
Vital to Department survival!

- BLM – endowed faculty, funding for recruiting
- DEA – $15,00 Scholarship match
- Topcon – GPS grant
- Leica – Software grant
- ODOT- robotic total stations
- Many others!

CHINESE PROVERB

- If you give a man a fish, he can eat today.

- If you teach a man how to fish, he can feed himself for ever.

GEOMATICS DEPARTMENT

The baccalaureate Surveying and GIS program options have the following objectives:

- Provide students with a broad foundation in major geomatics disciplines
- Prepare students to function effectively on multidisciplinary teams
- Prepare graduates to enter into professional practice
- Prepare graduates to become licensed or certified professionals

STATE PLANE COORDINATE SYSTEMS

Original design concept to limit distortion

Design of 1927 State Plane Coordinate System

- The SPCS 27 was designed by the U.S. Coast and Geodetic Survey in the 1930's.
- Distances were measured by stadia or taping, and generally did not exceed 1:10,000 accuracy.
- The maximum grid scale factor distortion did not exceed the accuracy of measured distances, 1/10,000
- Grid distance equals ground distance (at low elevations) **LIFE IS GOOD!**

Design of 1983 State Plane Coordinate System

- With the advent of the EDM and higher accuracy surveys, grid scale and elevation factors could seldom be ignored. **LIFE IS A BUMMER!**
- A few states changed projection types and/or zones.
- Montana uses a single zone with larger distortions. Corrections MUST be properly applied.

Design of 1983 State Plane Coordinate System

- Often, a “combined factor” can be used for small projects to convert ground distances to grid distances and visa versa if the grid and elevation scale factors did not change significantly. **LIFE IS A LITTLE BETTER!**

- The SPCS was designed to be simple, and provide a common coordinate reference in the national spatial reference system.

- Seems like a good idea, but **how many surveyors use the SPCS?**

GME 452 Map Projections

- Use the Gaussian differential equations of conformality to derive map projection properties & distortion principals.
- Study the State Plane Coordinate systems & write TM & Lambert conversion software
- Study Low-Distortion Map Projections

Comments on LDP's

- "The most important concept I learned at OIT. The basis for all of our firm's work."
- "XYZ state DOT would never allow us to use a LDP!"
- Prof. Dennis Findorff designed LDP's for several firms and agencies
- The majority of alumni report resistance to the concept

LOW DISTORTION PROJECTION

Hypothetical example to demonstrate the benefits of a LDP

Those Lucky Surveyors!

The ethereal city of Lucky is centered on the intersection of the Oregon South Zone SPCS central meridian, and the south standard parallel.

Lucky covers about 6 miles in extent, and the average elevation is 10 m above sea level.

Those Lucky Surveyors!

- The grid scale factor (GSF) is 1.0 along the south standard parallel
- At the edges of the city, the GSF is 0.9999895. If ignored, this introduces a systematic error of 1:125,000.
- The zone edges are the worst case scenario, and represent a distortion of acceptable for most projects.

Consider the Surveyor in Lucky, Oregon

- The elevation factor (EF) is 0.9999984. If ignored, this introduces an error of 1:640,000, negligible for almost all projects!
- For many projects, Lucky surveyors can use ground distances and angles as grid distances and angles. **LIFE IS SUPER!**
- Convergence at the eastern and western edges of Lucky is 0^{o} 02’ 24” and can’t be ignored.
- It is easy to rotate bearings. **LIFE IS STILL GOOD!**

EACH ONE OF ***<u>YOU</u>*** CAN GET LUCKY!

DESIGN A LOCAL MAP PROJECTION

- Select a projection type that best fits the project area.
  - Lambert for greater east-west extent
  - Transverse Mercator for greater north-south extent
  - Oblique Mercator for greater extent in another direction

LDP GOAL:
Use Grid Distance as Ground Distance

- Select the maximum GSF distortion which can be tolerated to determine the zone extent. For “small” projects, only one zone is needed.

- Select a “best fit” project elevation.

- Determine if the GSF, EF, and combined distortions are negligible for the intended application.

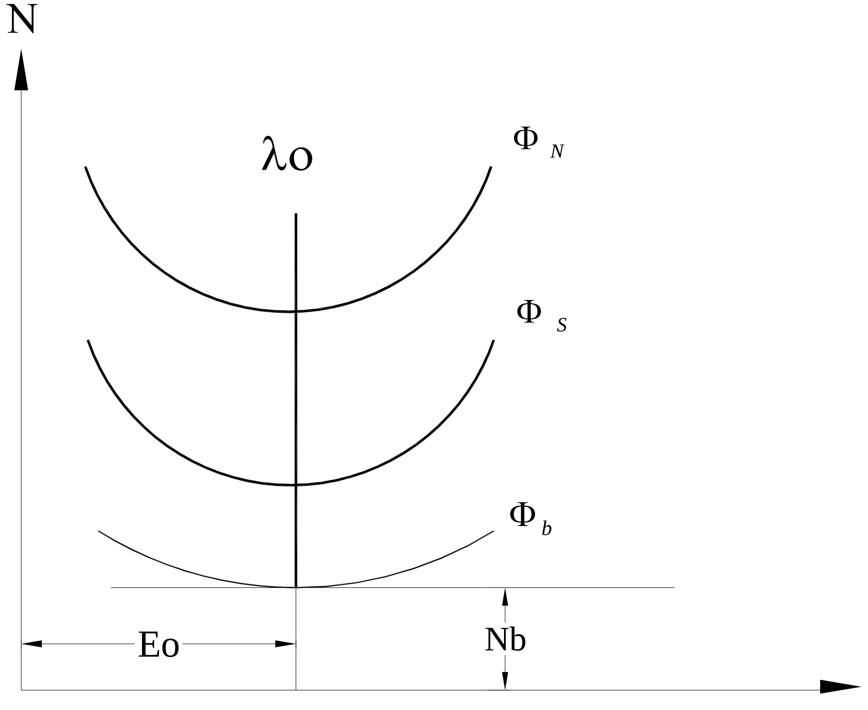
DESIGN A LDP PROJECTION

- Determine the zone parameters
- Lambert Zones
  - North standard parallel latitude
  - South standard parallel latitude
  - Latitude of the grid origin
  - North and east coordinates of the grid origin

Lambert Zone Definition

Lambert SPCS Zone Definition

GME 452 Map Projections



DESIGN A LDP PROJECTION

- Determine the zone parameters
- TM Zones
  - Longitude of the central meridian
  - Grid scale factor of the central meridian
  - Latitude of the grid origin
  - North and east coordinates of the grid origin

LDP DESIGN PARAMETERS

- Determine the zone parameters
- Oblique Mercator Zones
  - Azimuth of the central axis
  - Grid scale factor of the central meridian
  - Latitude of the grid origin
  - North and east coordinates of the grid origin

LDP DESIGN - ELEVATION

- Compute an average project elevation.
- Can the elevation factor distortion be ignored using this project elevation?
- If the answer is yes, design a custom ellipsoid to pass through this elevation

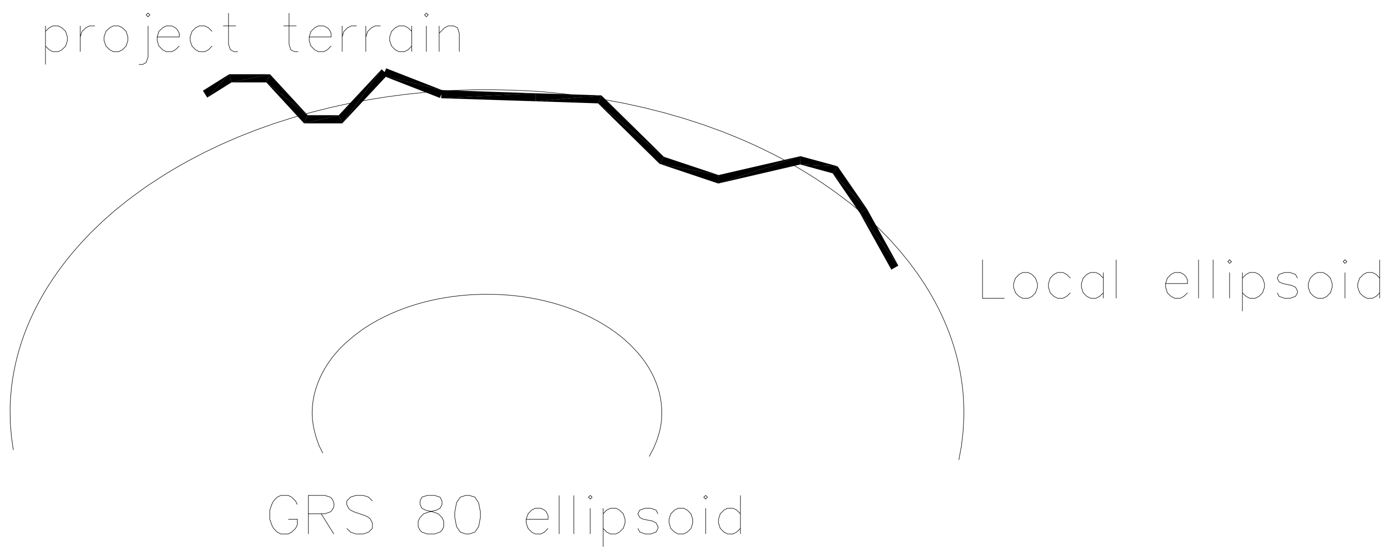
LDP DESIGN - ELEVATION

Design a custom ellipsoid

- Modify the GRS 80 ellipsoid semi-major axis “a” by adding the project elevation to obtain the project ellipsoid semi-major axis.

- Retain the flattening ratio of GRS 80 ellipsoid, $1/f = 298.257222101$. A geodetic position on the GRS 80 and project ellipsoid will have the same latitude and longitude.

Local Ellipsoid to Minimize EF Distortion



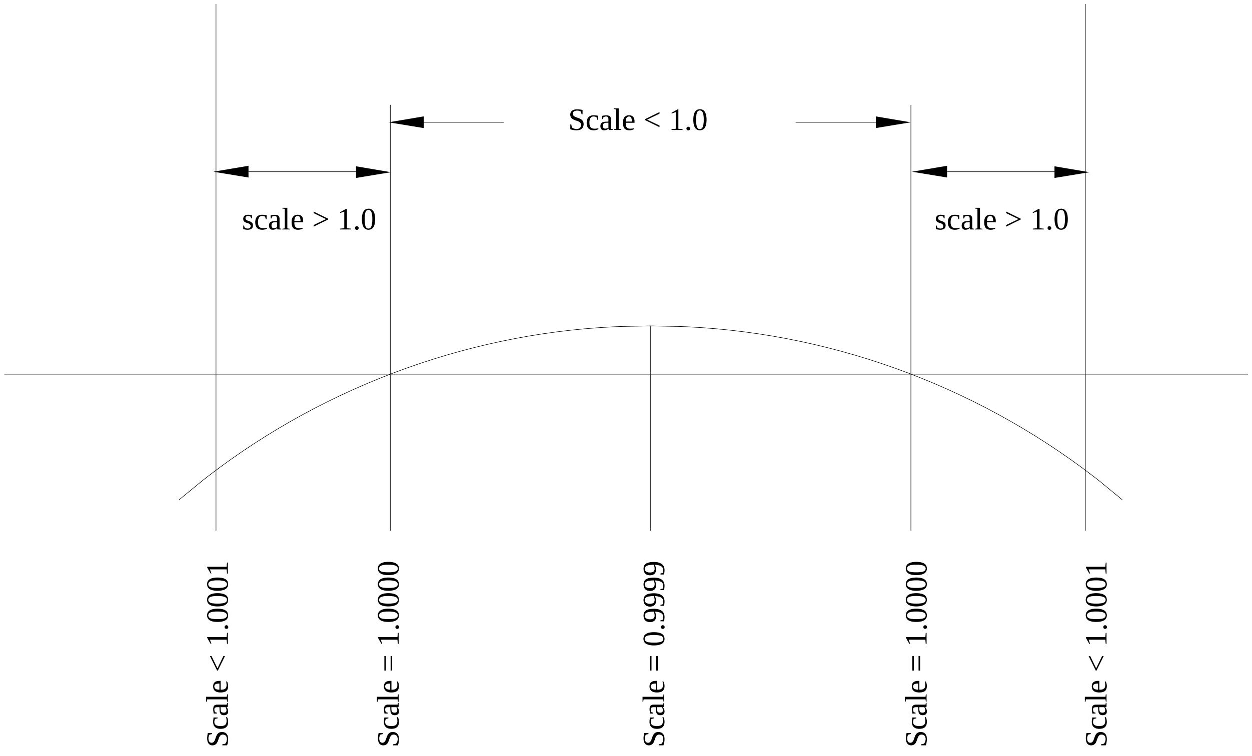
Elevation Difference vs. Distortion

	Distortion if Ignored		Max. Elev.
Elevation Factor	Ratio	PPM	Diff. (m)
0.9999	10,000	100	637.2
0.99999	100,000	10	63.7
0.999998	500,000	2	12.7
0.999999	1,000,000	1	6.4

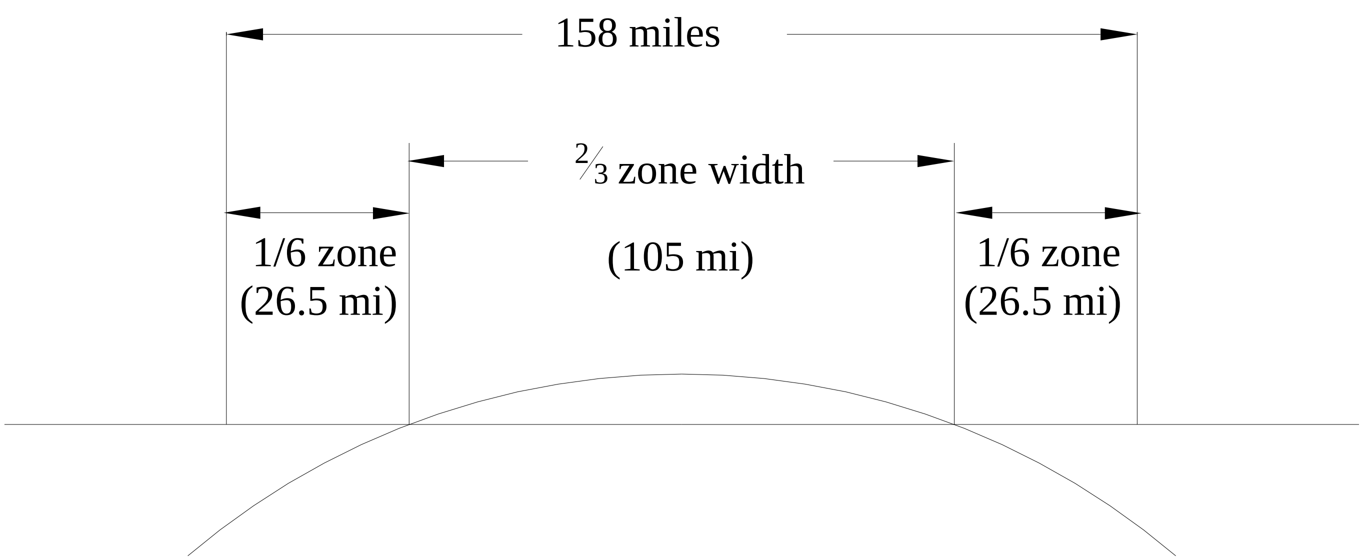
LPD ZONE DESIGN

- Based on acceptable maximum distortion, determine the zone extent.
- Based on project extent, determine zone type

Secant map projection with a maximum distortion of 1:10,000



Zone Extent with 1:10,000 Maximum GSF Distortion

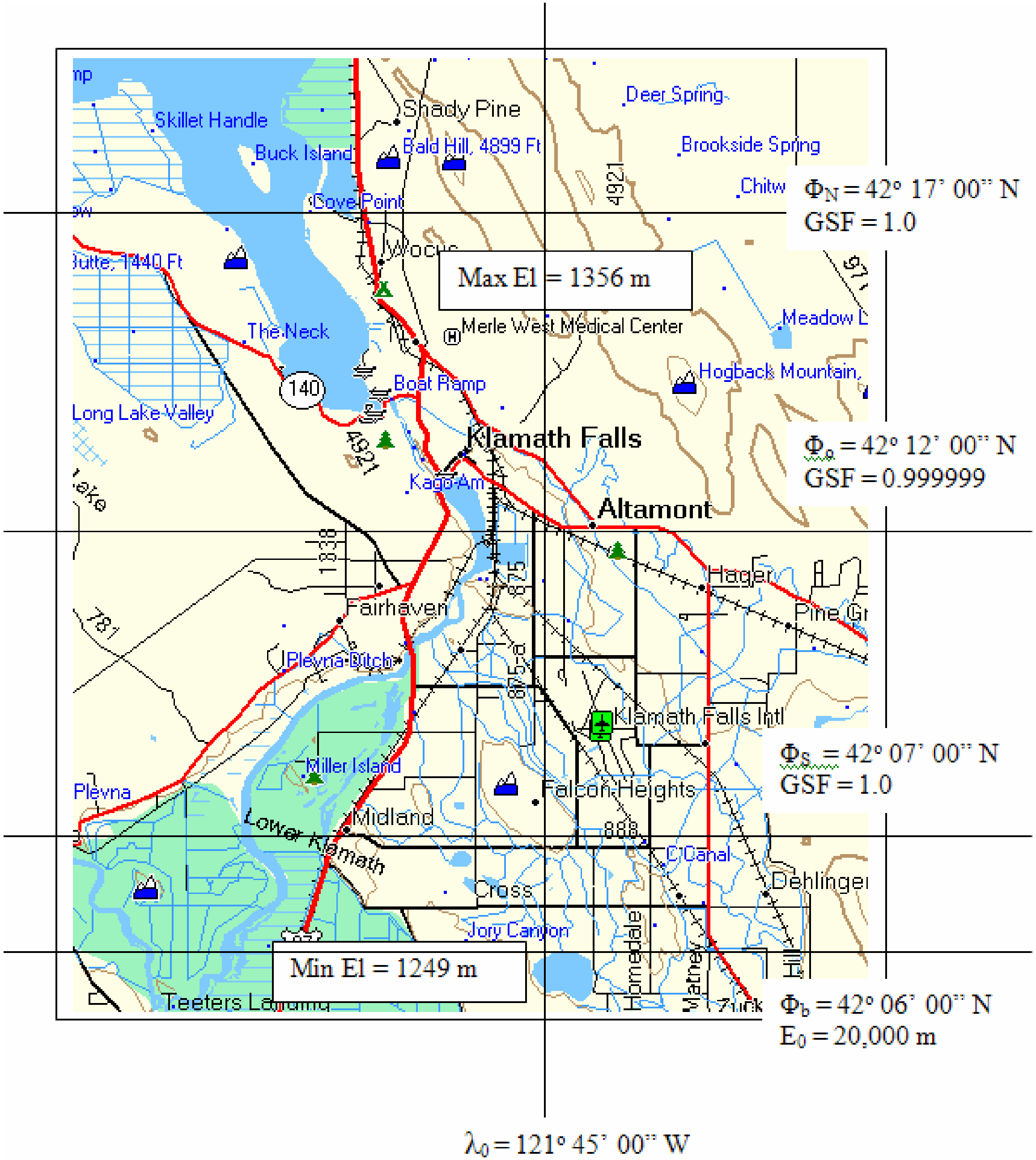


Zone Extent vs. GSF Distortion

Maximum Grid Scale Factor for Zone Center	Maximum Distortion	Approx. Separation of Lambert Std. Parallels	Total Zone Width (km) – (mi)
0.9999	1:10,000	1^{0} 37’	254 km – 158 mi
0.99999	1:100,000	0^{o} 31’	80 km – 50 mi
0.999998	1:500,000	0^{o} 14’	36 km – 22 mi
0.999999	1:1,000,000	0^{o} 10’	26 km – 16 mi

Klamath Falls LDP

- Designed to allow use of grid distance as ground distance for a 16 mile zone.
- Max. GSF = 0.999999 or 1.000001 which is a 1:1,000,000 distortion if not applied.
- Reference elevation is 1311. m
- Max EF is 0.9999904 which is a 1:104,000 distortion if not applied.
- Elevations over 1375 m will have distortion greater than 1:100,000, EF must be considered.



Φ_N = 42° 17' 00" N
GSF = 1.0
Φ_o = 42° 12' 00" N
GSF = 0.999999
Φ_S = 42° 07' 00" N
GSF = 1.0
Φ_b = 42° 06' 00" N
E_0 = 20,000 m
Max El = 1356 m
Min El = 1249 m
λ_0 = 121° 45' 00" W
Skillet Handle
Buck Island
Shady Pine
Bald Hill, 4899 Ft
Deer Spring
Brookside Spring
Cove Point
Butte, 1440 Ft
The Neck
Merle West Medical Center
Meadow L
Hogback Mountain
Boat Ramp
140
Long Lake Valley
Klamath Falls
Kago Am
Altamont
Hager
Pine Gr
Fairhaven
Plevna Ditch
Klamath Falls Intl
Miller Island
Plevna
Falcon Heights
Midland
Lower Klamath
C Canal
Dehlinger
Cross
Jory Canyon
Homedale
Matney
Teeters Landing
4921
1338
781
875
875-a
888

Converting local coordinates to state plane coordinates

- Local north and east coordinates can be converted to geodetic latitude, longitude coordinates using the NGS Manual 5 map projection formulas with the custom projection zone definitions.
- Geodetic coordinates can then be converted to state plane coordinates. There is no loss of accuracy if the conversions are done correctly.

Converting local coordinates to state plane coordinates

- Many software packages allow custom ellipsoids and map projections to be defined.
- This automates computations and makes use of local coordinate systems straightforward.
- Users are still working in the National Spatial Reference System (NSRS)!

REFERENCES

- **SURVEYING Theory and Practice**, 7th edition, Anderson, Mikhail
- *Design of a Local Coordinate System for Surveying, Engineering, and LIS/GIS*, Earl Burkholder SALIS, vol. 53, No. 1, 1993
- **NOAA Manual NOS NGS 5 State Plane Coordinate System of 1983**, Stem

Now <u>**YOU**</u> too can get LUCKY!

Thank you for your time!