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Highlight Article

The National Elevation Dataset

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The National Elevation Dataset (NED) is a seamless raster product produced by the U.S. Geological Survey (USGS). The NED provides elevation data coverage of the continental United States, Alaska, Hawaii, and the island territories in a seamless format with a consistent projection, resolution, elevation units, and horizontal and vertical datums. The NED is the result of the maturation of the USGS elevation production program (Osborn and others, 2001), in which national coverage of quadrangle-based digital elevation models (DEM) has been completed.

Requirements from a User's Perspective

To illustrate the advantages of seamless, large-area coverage of elevation data versus existing tiled databases, the following scenario is presented from a user's perspective. The user has a requirement to conduct a regional hydrologic modeling study within the area covering the headwaters of the Upper Colorado River basin along the continental divide in southwest Wyoming (Figure 1). The study is to make use of digital elevation data and derived hydrologic products. There are two approaches to preparing the geospatial data needed for the study, and the efforts required on the part of the user differ significantly in each approach. Table 1 (shown on page 7) compares the steps taken by the user in each approach to get to the point where hydrologic modeling work can begin.

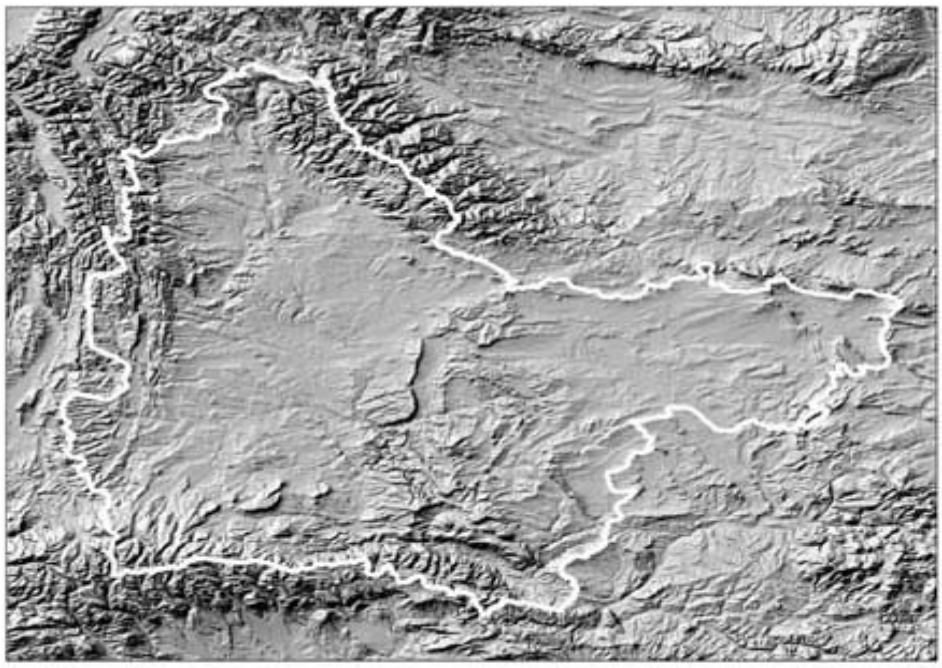

Figure 1. Upper Colorado River headwaters region

This scenario is hypothetical, but the number of files and processing steps listed under the tiled database approach are accurate and are based on the current holdings in the USGS 7.5-minute DEM database. As is shown, all the DEM preprocessing required for tiled data is eliminated in the seamless NED approach. The final steps of preparing hydrologic products from the elevation data as listed are being addressed by an effort parallel to NED, the USGS Elevation Derivatives for National Applications (EDNA) project (Verdin, 2000; Kost and Kelly, 2001).

Background, Rationale, and History

An important aspect of the National Spatial Data Infrastructure (NSDI) is that of the digital geospatial data framework. The framework approach is a collaborative one in which the data themes most commonly needed by geographic data users are produced by several organizations, integrated into coherent datasets, and shared by numerous users. Framework data are the "best available" data that meet a common standard, and they provide a base layer for many applications of geospatial data. The Subcommittee on Base Cartographic Data of the Federal Geographic Data Committee (FGDC) is charged with the coordination of NSDI framework data activities among Federal agencies. One of the seven framework data themes is elevation, and the USGS has been designated as the agency having lead responsibility for national elevation data. As such, the USGS has assembled NED as an implementation of the framework data concept.

Because the USGS produces elevation data that match the quadrangle format of the standard base map series for the United States, most users must access and use multiple files of digital elevation data, usually in 7.5-minute tiles, to construct the elevation layer for their study areas. Many times, owing to the age of the data and the manner in which they were produced, there are challenges in assembling the DEM tiles, as illustrated in the scenario above. For instance, when the user is working with 7.5-minute DEMs in their native Universal Transverse Mercator (UTM) projection, a UTM zone boundary may cross the study area, thus adding the requirement for some of the elevation data to be reprojected into a zone common with the majority of the DEMs. In addition, when DEM files are mosaicked, sometimes the adjacent tiles do not match correctly owing to slivers of missing data, large vertical offsets, or differences in elevation units. Some of the oldest 7.5-minute DEMs were produced with photogrammetric methods (Brunson and Olsen, 1978; Kelly, McConnell, and Mildenberger, 1978) that resulted in striping artifacts in the data. Because the artifacts can have a detrimental effect on derivative products and applications, many users have developed various approaches to filter the DEMs in an effort to reduce or remove the artifacts (Brown and Bara, 1994; Garbrecht and Starks, 1995). In total, users may have to do a significant amount of data processing just to construct an acceptable elevation layer for their geospatial databases. In an effort to better meet the needs of data users for application-ready products, the USGS has produced and is continually maintaining the NED, thereby removing the need for users to repeatedly perform preprocessing steps to make the DEMs suitable for geographic information system (GIS) use. This approach fits well with the framework concept, in which the "best available" data are easily accessible to all and unrestricted sharing of quality spatial data among users facilitates a wide range of applications.

Table 1. Alternative approaches to preparing elevation data for a regional study.

Tiled DEM Database	Seamless Elevation Dataset
User employs EarthExplorer to identify "best available" DEMs.	User employs Web browser to view seamless elevation dataset
User downloads 476 30-meter SDTS format DEMs	User interactively selects areas of interest and enters order information
User orders 408 10-meter DEMs. User receives 408 files on tape, CD or by ftp	User receives one elevation data file and associated derivative products and metadata files on CD or by ftp
User imports 884 DEM files	User imports data
User converts elevation units of 12 DEMs from feet to meters	
User filters 221 30-meter Level 1 DEMs to remove production artifacts that would affect derivative products	
User projects 234 30-meter DEMs from UTM zone 13 to UTM zone 12	
User mosaics 476 30-meter DEMs	
User mosaics 408 10-meter DEMs	
User resamples 10-meter DEM mosaic to 30-meter grid spacing	
User merges to 30-meter mosaics to produce uniform elevation data coverage of the study site	
User smooths data discontinuities along quadrangle boundary seams with various image processing tools	

User projects merged elevation dataset to an equal-area projection in NAD83 horizontal datum	
User generates derivative products: slope, aspect, drainage basins, subwatersheds, streamlines	
User edits elevation dataset and regenerates derivative products. User repeats process as necessary until proper hydrological conditions are represented	
User begins hydrologic modelling study	User begins hydrologic modelling study

The USGS began the development of seamless elevation datasets in the early 1990s, first working on continental and global datasets at a resolution of 1 kilometer. The experience gained in assembling multisource, multiresolution elevation data into a global seamless dataset proved to be valuable as the methods were adapted, refined, and further developed for use in producing regional U.S. elevation framework prototypes in 1996. The first complete seamless coverage of the continental United States was finished in 1997 and was based on 10-meter, 30-meter, 2-arc-second, and 3-arc-second resolution source data. In 1999, for the first time, the NED was assembled completely (for the continental United States) from 7.5-minute DEM source data (10-meter and 30-meter data).

NED Specifications and Production

To be a truly seamless dataset, the NED is assembled using a raster data model cast in a geographic coordinate system (horizontal locations are referenced in decimal degrees of latitude and longitude). A consistent grid spacing of 1-arc-second (approximately 30 meters) is used, except for Alaska, where lower resolution source data warrant the use of a 2-arc-second spacing. Elevation units are standardized to decimal meters. The horizontal datum for NED is the North American Datum of 1983 (NAD 83), and the vertical datum is the North American Vertical Datum of 1988 (NAVD 88). FGDC-compliant metadata are provided for efficient documentation. Additionally, spatially referenced metadata are supplied as an attributed geospatial data layer that captures all metadata from the source DEMs and NED processing stages on a quadrangle basis.

The NED is a logically seamless dataset, as computer-processing considerations require that the data be assembled on a tiled basis, and the tiles collectively form the virtual national mosaic. Currently, NED production uses a 1- by 1-degree tile as the unit for assembly and processing of source DEMs. Adjacent tiles are edge matched to ensure the seamless nature of the entire national dataset. In its entirety, the NED comprises almost 1,400 1- by 1-degree tiles, with over 900 tiles covering the continental United States, nearly 400 covering Alaska and Hawaii, and the remainder covering the island territories. The total data volume for the NED currently approaches 60 gigabytes.

The NED is assembled from approximately 57,000 files of quadrangle-based source DEMs. As source data for NED production, nearly 54,000 DEMs are used for the continental United States and about 3,000 DEMs for Alaska, Hawaii, and the island territories. Production of 7.5-minute DEMs, especially at the 10-meter posting interval, is an ongoing activity at the USGS, so the NED is updated on a regular basis to incorporate all new DEM production, thus retaining the “best available” framework concept. A new version of the NED is released every two months, containing updated areas for which new source DEMs became available since the previous release. On average, approximately 20% of the 1- by 1-degree tiles are updated at each release. An update is required for a tile if even one new DEM is available, as edge matching must be done to ensure the seamless quality of NED. The spatially referenced (quadrangle-based) metadata provided with each NED release indicate the specific areas where new source DEMs have been incorporated since the previous release.

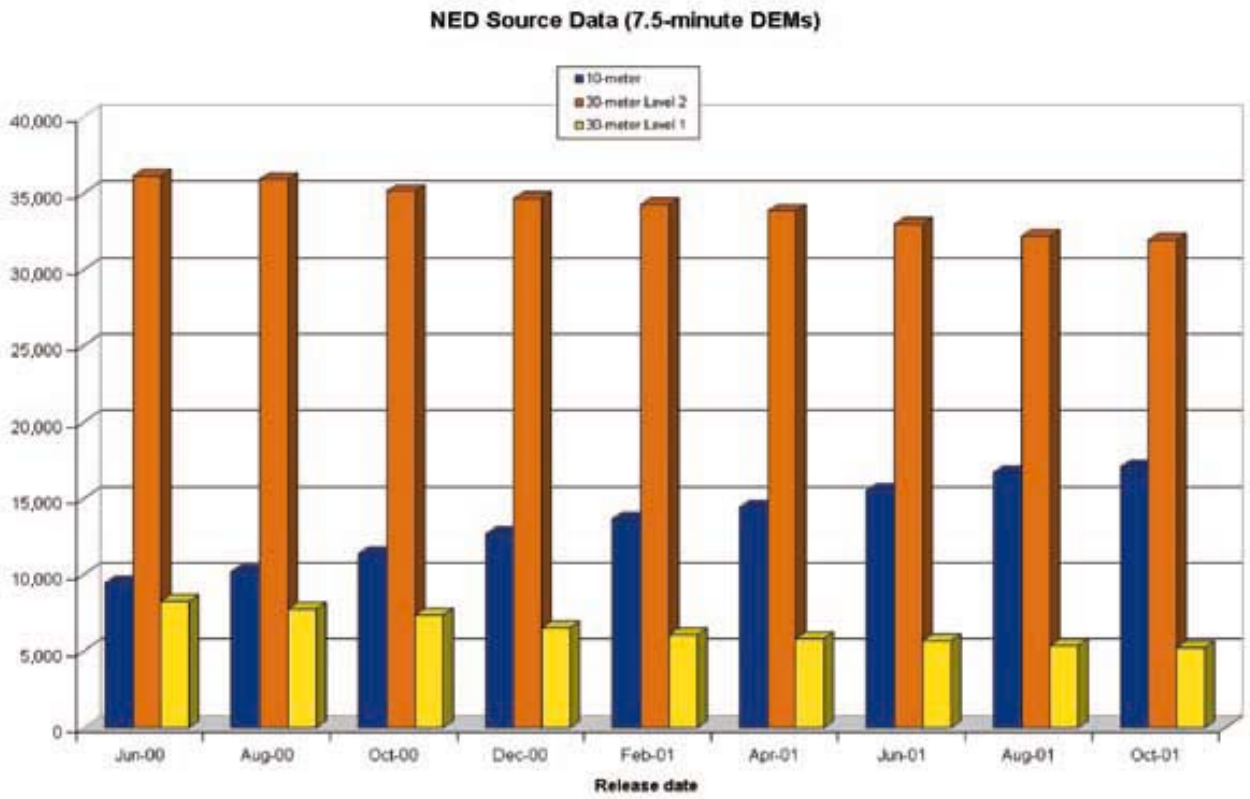

Figure 2. Source data (by DEM type) for recent NED releases.

When a NED tile is assembled, the best available source data are selected according to the following criteria (ordered from first to last): 10-meter DEM, 30-meter Level 2 DEM, 30-meter Level 1 DEM, 2-arc-second DEM, 3-arc-second DEM. For the continental United States, the number of 10-meter source DEMs is increasing continually, so the number of 30-meter DEMs used in NED production has been decreasing correspondingly. Currently, for the continental United States, over 30% of the NED is derived from 10-meter source DEMs, and less than 10% is derived from the older 30-meter Level 1 DEMs, with the remaining 60% of the area based on the 30-meter Level 2 DEMs. Figure 2 shows the source data by DEM type for recent NED releases.

An interactive map server on the NED Web site (Figure 3) allows a user to display the NED data source index, which indicates the date of the most recent update, the resolution of the source data, and the production method of the source data for specific areas. The user can also query the spatially referenced metadata to examine additional information about each quadrangle-based DEM used to assemble the NED. The NED Web site also contains documentation on the NED assembly process, accuracy, metadata, standards, and data distribution.

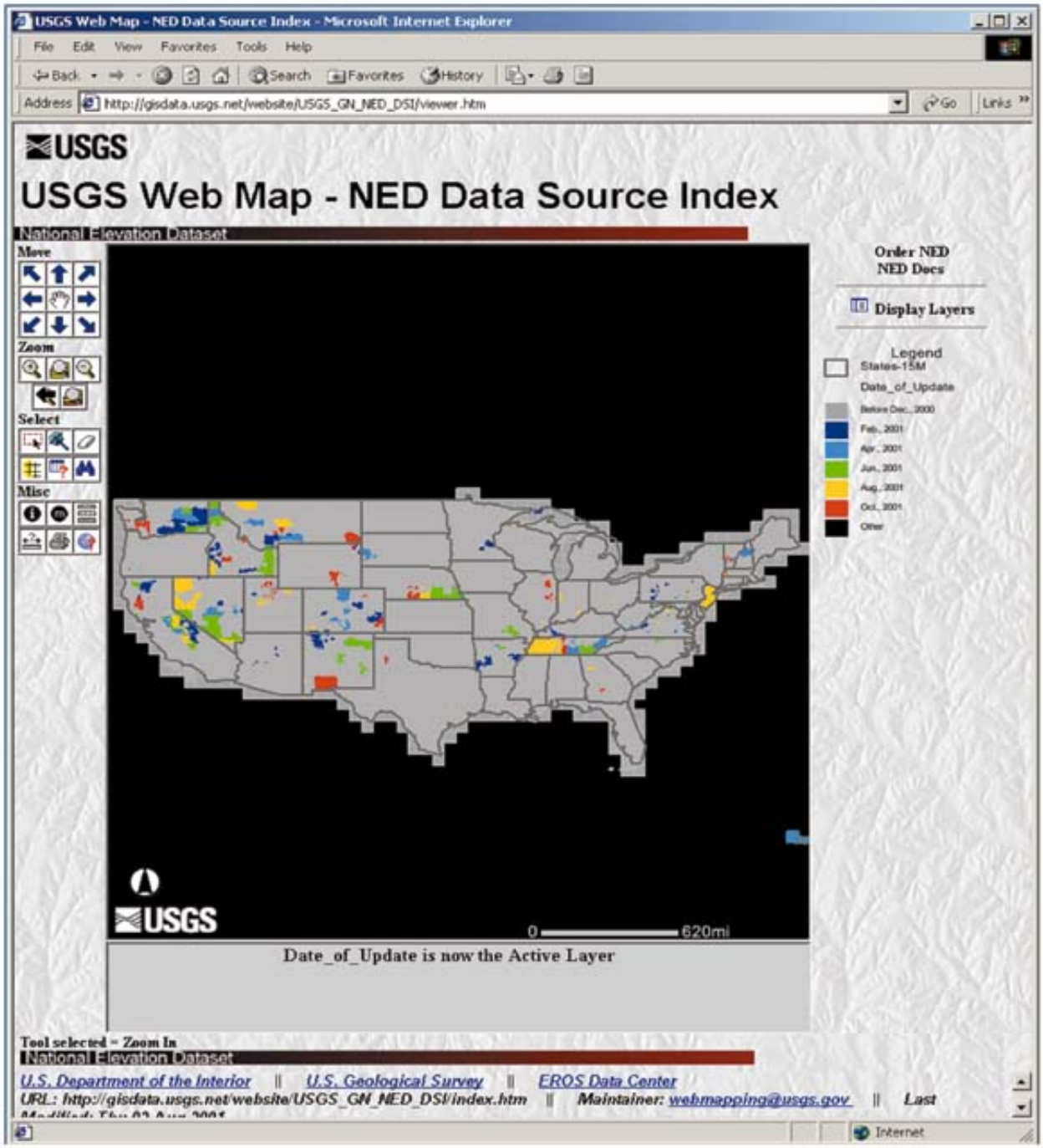

Figure 3. Data source index on NED Web site at http://gisdata.usgs.gov/ned/.

NED assembly and updating are accomplished with a highly automated production process that was developed specifically for this seamless elevation dataset. The main steps in the process are outlined in Figure 4. The selection of source data is accomplished by an automated query of the USGS National Mapping Program's Sales Database (SDB), known to the public as USGS GeoData. The "best available" data criteria outlined above are applied to select specific quadrangle-based DEMs from the SDB. The headers of the selected DEMs are read to create an "index," which controls production and triggers subsequent processing steps. Industry standard tools from the National Geodetic Survey (NGS), NADCON and VERTCON, are used to perform horizontal and vertical datum transformations, respectively.

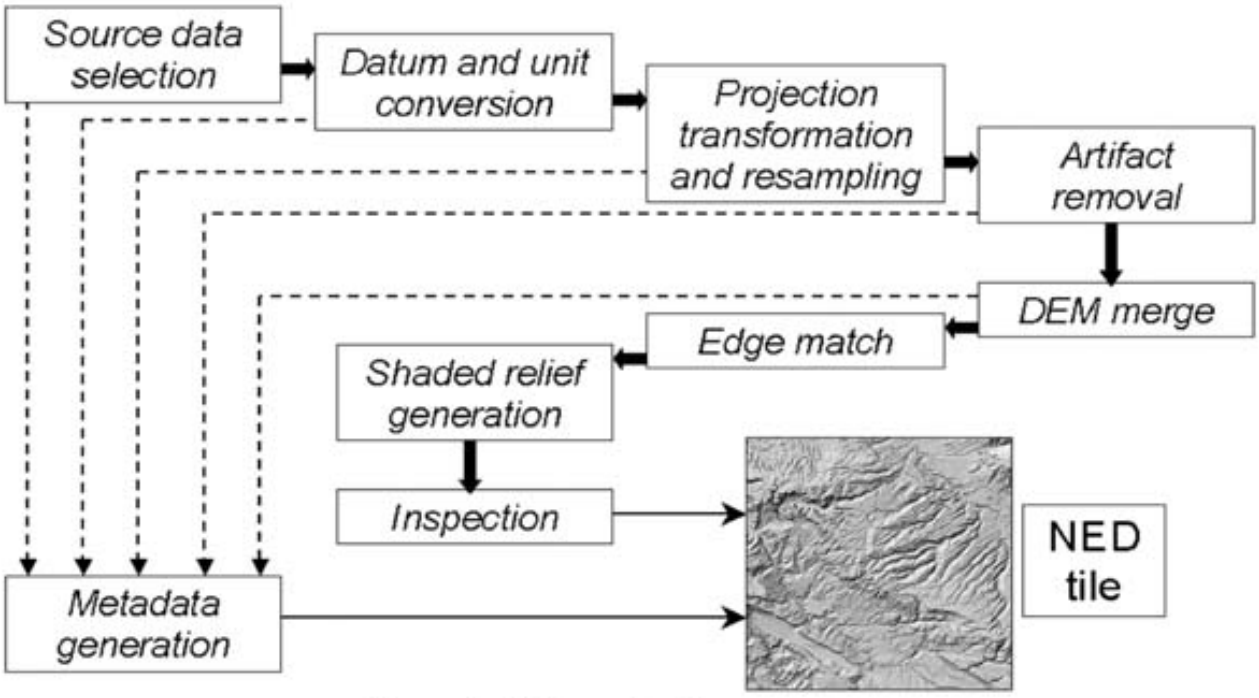

Figure 4. NED production process

The 7.5-minute source DEMs are reprojected from their native UTM coordinate system to a geographic coordinate system (decimal degrees of latitude and longitude) using standard cartographic transformation software. Resampling of the original elevation values is done with an implementation of cubic convolution that is optimized for elevation data by maintaining the integrity of shorelines and water bodies. Artifact removal is performed on the older Level 1 DEMs that were produced with photogrammetric methods. The “mean profile filter” (Oimoen, 2000) was specifically designed to process these 7.5-minute DEMs. The filter process uses a series of directional filters to isolate the high-frequency artifacts, which are then subtracted from the DEM. The magnitude of these artifacts is small, typically less than 1 meter, so the change to the DEM is negligible, but the removal results in significant improvements in derivative elevation products, such as shaded relief, slope, and aspect (Figure 5).

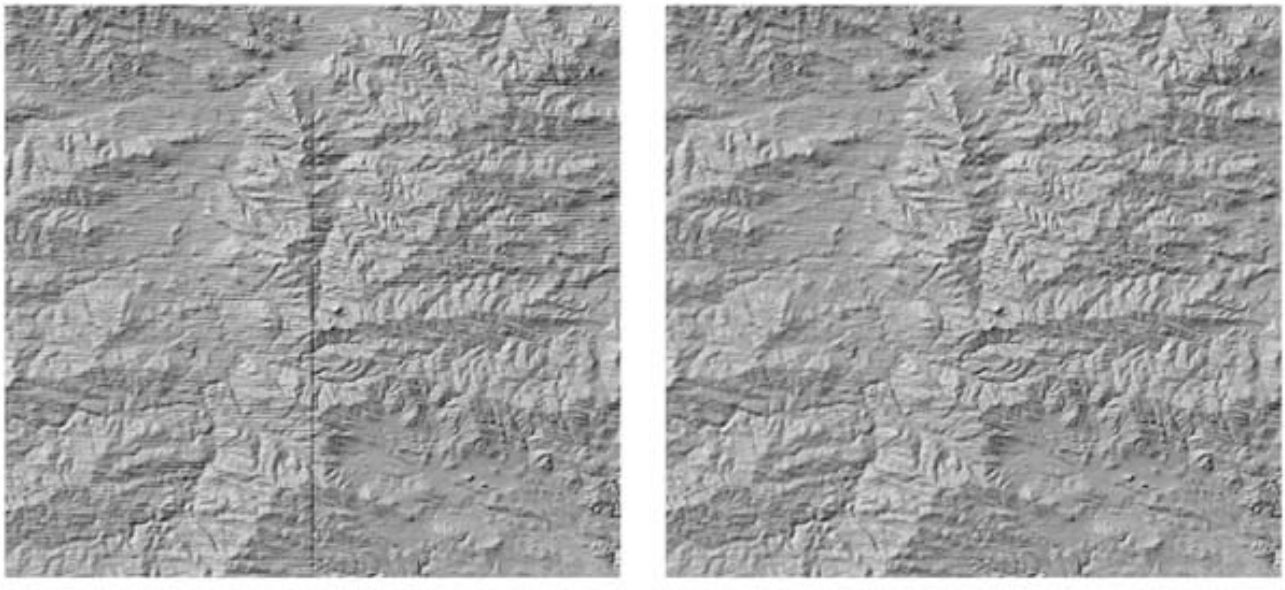

Figure 5. Source DEMs without artifact filtering and edge matching (A, shown on the left), and NED data with artifact filtering and edge matching (B, shown on the right).

The final steps in the production process include paneling the DEMs to fill the 1- by 1-degree tile, filling slivers of missing data along DEM boundaries as necessary by interpolating adjacent values, and edge matching the seams along the DEM

boundaries and tile edges. The edge match algorithm uses a feathering approach that maintains local slope continuity across the seam. Finally, a shaded-relief image of the tile is generated for inspection by an analyst to verify successful processing, especially artifact filtering and edge matching. In some cases, DEM header information, which automatically triggered certain processing options, was incorrect, and the result is data that are not acceptable for inclusion into the NED. These cases are detected in the visual inspection step, the DEM header is corrected, and the tile is submitted for reprocessing. Tiles passing inspection are transferred to the next release version, and the spatially referenced metadata are updated accordingly.

Data Distribution

In keeping with the framework concept of easily accessible data, NED products are available in several common formats through a Web-based seamless data distribution system (Figure 6) linked to the NED home page. The system uses interactive map server technology to provide users the capability for viewing shaded-relief images derived from the NED. The map server also includes numerous reference layers, including the NED spatially referenced metadata, to help users define their study areas. The system incorporates a geographic names capability wherein users can automatically pan and zoom to specific feature locations. The user enters customer and order information interactively, and orders for products resulting in network-compatible file sizes can be delivered electronically to the user. Orders for larger areas are produced on hard media for the cost of reproduction and shipped to the customer.

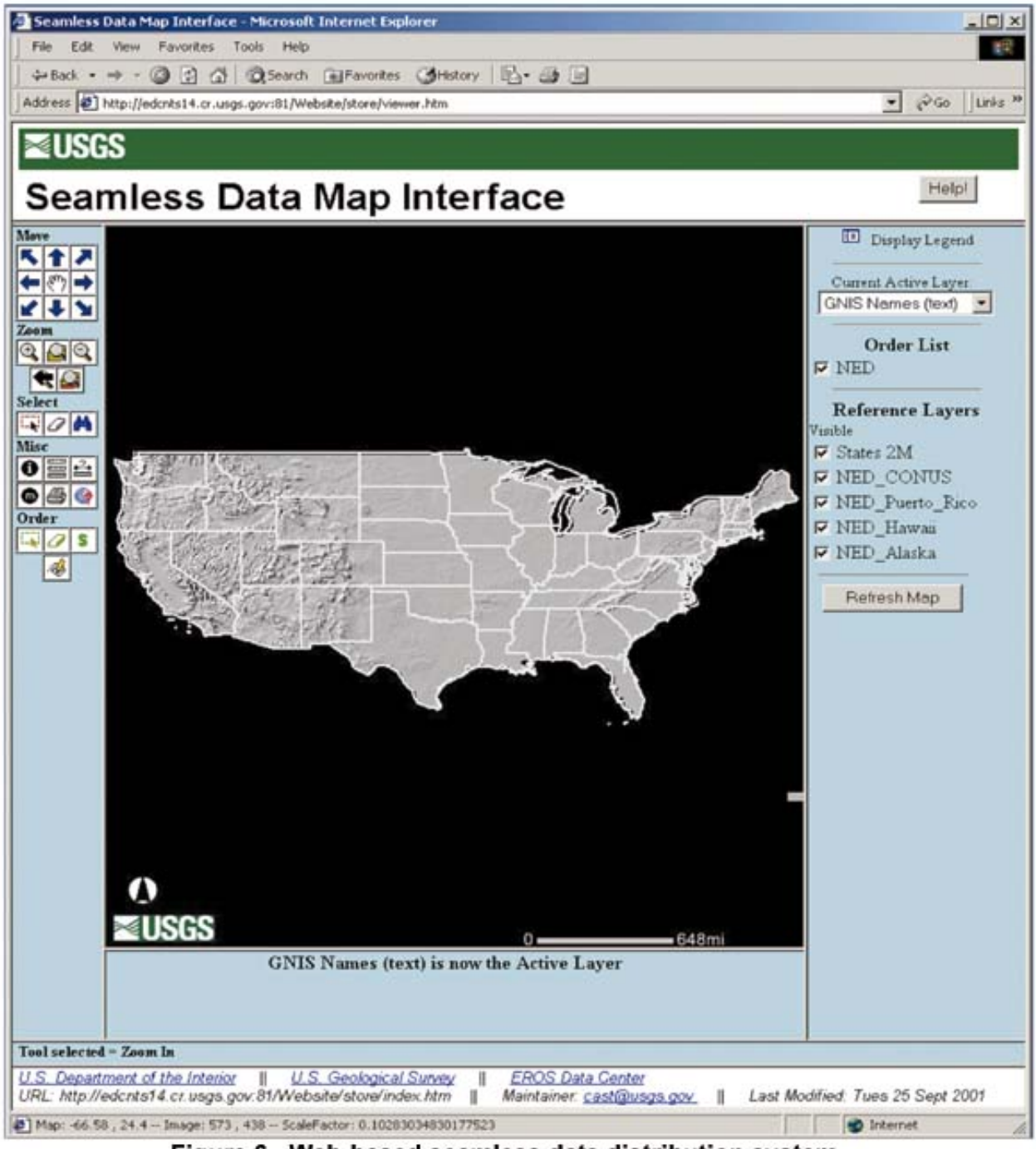

Figure 6. Web-based seamless data distribution system

Figure 6. Web-based seamless data distribution system for viewing, ordering, and delivering of NED products.

Current Development

Several NED development activities are currently underway to enhance the seamless elevation data available to users. The NED production system has been modified to produce 1/3-arc-second data, thereby maintaining the full information content of the 10-meter source DEMs. Currently, 1/3-arc-second data are being produced only where there is full coverage of 10-meter source DEMs for an entire 1- by 1-degree NED tile. This results in multiresolution NED products being available over certain areas. In these areas, both 1-arc-second and 1/3-arc-second data are produced with the same characteristics and are "nested" spatially to facilitate easy transition between resolutions.

A second area of current research and development is the integration of source data other than standard USGS DEMs into the NED. Researchers in the USGS elevation program are actively evaluating new elevation data collection technologies, including LIDAR, IFSAR, and softcopy photogrammetry (Osborn and others, 2001). DEMs resulting from these newer production methods generally have higher resolution and accuracy than existing DEMs. To maintain the "best available" characteristic of the NED, the USGS must exploit and incorporate these new sources into the NED, especially in those areas where applications are limited by existing source data, such as low-relief coastal areas.

Accuracy assessment and reporting for the NED is another topic being actively pursued. The accuracy of the NED varies spatially because of the variable quality of the source DEMs. As such, the NED "inherits" the accuracy of the source DEMs. Some accuracy statistics are available in the source DEM headers, and this information is captured in the spatially referenced metadata. Many times this accuracy information has limited usefulness because it is a relative measure of how well the DEM fits the source material from which it was generated. In an effort to provide more information to users on the absolute vertical accuracy of the NED, the USGS is testing the NED by comparing it with an independent reference source of very high accuracy. The reference data are the geodetic control points that form the High Accuracy Reference Network (HARN) maintained and distributed by the NGS. Nationally, almost 6,000 HARN points are available, so they are an excellent high-quality reference dataset for assessing the NED. Use of the NED spatially referenced metadata also allows the calculation of accuracy statistics by source DEM characteristics, including resolution, level, age, contour interval, and production method. Land surface characteristics derived directly from the NED, including elevation, slope, aspect, and local relief, allow for examining accuracy as a function of specific site conditions. The use of other independent reference data for accuracy assessment, including control points from digital orthophoto production projects, is also being investigated. Future plans call for updating overall accuracy statistics with each NED release and for providing accuracy estimates for specific areas ordered by the customer as part of the delivered metadata.

Summary

The NED is a seamless raster dataset from the USGS that fulfills many of the concepts of framework geospatial data as envisioned for the NSDI, allowing users to focus on analysis rather than data preparation. It is regularly maintained and updated, and it provides basic elevation data for many GIS applications. The NED is one of several seamless datasets that the USGS is making available through the Web. The techniques and approaches developed for producing, maintaining, and distributing the NED are the type that will be used for implementing the USGS National Map (http://nationalmap.usgs.gov/).

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