TECHNICAL BRIEF

Note on the Use of USGS Level 1 7.5-Minute DEM Coverages for Landscape Drainage Analyses

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Introduction

The intuitively appealing notion to define topographic characteristics of complex landscapes from digital elevation models (DEMs) has lead to numerous DEM evaluation procedures and applications. In the field of hydrology and water resources, landscape characterization has focused predominantly on the definition of the drainage network, drainage divides, flow paths, and local slope and aspect (Band, 1986; Fairfield and Leymarie, 1991; Jenson and Domingue, 1988; Martz and Garbrecht, 1992; O'Callaghan and Mark, 1984; Skidmore, 1990). Given the success of previous applications (Jenson, 1991; Moore *et al.*, 1991; Quinn *et al.*, 1991; Tribe, 1991), the authors intended to investigate the characteristics of depressional wetlands and their contributing drainage areas in south central Nebraska using available USGS 7.5-minute DEM coverages. However, limitations in the DEM coverages prevented the proposed investigation of depressional wetlands. The authors experience with their application of Level 1 7.5-minute DEMs is reported here. First, the limitations and systematic errors in the DEMs representing the region under consideration are illustrated, and their impact on the drainage analysis is exemplified. Second, the reasons for the unsuccessful application are discussed and a simple, custom-produced DEM coverage is presented. The intent of the paper is to caution hydrologists and hydraulic engineers in the indiscriminate use of certain DEMs, and to expose the need for hydrographically consistent DEMs for drainage analyses.

DEM Coverages

Clay County in south central Nebraska was selected for the depressional wetland investigation. The region is characterized by low relief (on the average, a 15-m vertical change over a horizontal distance of about 10 km) and numerous wetlands ranging in size from a few to several hundred hectares. The USGS 7.5-minute topographic quadrangles and the corresponding DEM coverages for the geographic area under investigation are listed in Table 1. On the topographic quadrangles, depressions are defined by hachured contours as illustrated for the northeast corner of the Fairfield quadrangle (Figure 1). The hachured contours that define depressions are highlighted by thicker lines. Several depressions are deep enough to require two 10-ft contours for their full vertical definition (Figure 1). The largest depression, Massie Lagoon, which is the focus for the remainder of the discussion, is defined by single hachured lines below the 1760-ft contour and by double hachured lines below the 1750-ft contour. The outlines of the depression are generally smooth and well defined, and the contributing areas can be inferred from the contours surrounding the depressions. Drainage channels outside the depression are easily recognized by contour crenulation and the denser contours that define valley sides (lower left corner in Figure 1). Given the unambiguous definition of the drainage features on the topographic quadrangles and the significant depth of the depression, a numerical analysis of the topography using available USGS 7.5-minute DEM coverages was attempted in order to automatically define the location, extent, size, and shape of the depression and its contributing area.

Computer display of the USGS 7.5-minute DEM coverages in Table 1 show consistent and systematic east to west striping. The DEM coverage for the Fairfield quadrangle is shown in Figure 2. The striping is characterized by the irregular occurrence of alternating light and dark lines, each being approximately 90 m wide. Lighter shades indicate higher terrain, and darker shades lower terrain. The striping is particularly visible in the northeastern, western, and southeastern portion of the coverage (Figure 2). The absence of the striping on the topographic maps and the regularity with which they appear in the DEM display suggests that they are artifacts of the DEM.

The impact of the striping on the proposed automated wetland analysis, and on drainage studies in general, is threefold. First, the outline of drainage features, such as depressions or drainage paths, is not well defined. Smooth outlines that have a north-south direction (perpendicular to the striping) are often represented in the DEM as ragged lines having east-west indentations of about 90 m width. For example, the outline and the shape of Massie Lagoon in the DEM coverage are difficult to identify. The DEM coverage suggests that the lagoon is a parallel sequence of shallow trenches. Second, drainage paths are systematically biased in the east-west direction because of the flow draining into and following the stripes that identify a lower elevation. And third, the striping may introduce apparent drainage blockage for drainage paths that have a north-south flow component. These apparent drainage blockages can produce many artifi-

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TABLE 1. USGS 7.5-MINUTE TOPOGRAPHIC QUADRANGLES AND CORRESPONDING DEM COVERAGES FOR THE REGION UNDER INVESTIGATION.

Quadrangle Name	Contour interval in feet
Trumbull, Nebraska	5
Hasting East, Nebraska	5
Pauline, Nebraska	10
Lawrence, Nebraska	10
Fairfield, NW, Nebraska	10
Harvard NW, Nebraska	5
Inland, Nebraska	5
Harvard NE, Nebraska	10
Harvard, Nebraska	5
Fairfield, Nebraska	10
Fairfield SE, Nebraska	10
Deweese, Nebraska	10

cial depressions, some of which reach considerable size as exhibited in the Fairfield DEM coverage (Figure 3). According to the elevations given by the DEM, approximately 20 percent of this coverage consists of depressions. Many of the depressions follow major channels, indicating that the channels are continually blocked by the artificial striping in the DEM. On the other hand, the depression area on the USGS 7.5-minute topographic quadrangles is only about 5 percent. Taken together, the above three effects of the striping on drainage features render the available USGS 7.5-minute DEM coverages listed in Table 1 unusable for the depressional wetland investigation.

Sources of Systematic DEM Error

The source of the striping is related to the DEM production technique. All 12 DEM coverages used in the wetland investigation were developed using manual profiling from photogrammetric stereomodels of National High-Altitude Photography. In this production technique, profiles are usually scanned at 90-m separation, with elevations recorded at varying intervals depending on terrain characteristics (U.S. Geological Survey, 1990). The scan proceeds from east to west and then from west to east, and so forth until the coverage is completed. The striping introduced by the manual profiling is a combination of human and algorithmic errors (B. Kunert, U.S. Geological Survey, personal communication, 1993). The human error results from the slightly different perception the technician has of the ground as he/she scans either from east to west, or from west to east. The algorithmic error is introduced by the interpolation algorithm for elevations between the scanned profiles. Together, these errors result in the observed systematic and identifiable striping shown in Figure 2 (B. Kunert, U.S. Geological Survey, personal communication, 1993).

The DEMs produced by manual profiling from photogrammetric stereomodels are classified as Level 1 DEMs. The desired accuracy standard for Level 1 DEMs is a vertical root-mean-square error (RMSE) value of 7 m, with a maximum permitted value of 15 m. An absolute elevation error tolerance of 50 m relative to the true height from mean sea level is set for blunders for any grid node. Also, an array of 49 contiguous elevation points shall not be in error by more than 21 m. It is also emphasized that systematic errors within the stated accuracy standards are tolerated (U.S. Geological Survey, 1990). These include the previously discussed striping. Many of the Level 1 DEMs were developed in the 1970s at a time when today's modern and accurate techniques were not available. DEMs that are developed today are generally derived from Digital Line Graphs (DLGs) and are processed for consistency and edited to remove identifiable systematic errors. These DEMs are classified as Level 2 and do not exhibit the above described problems. However, it is important to note that the majority of the available USGS 7.5-minute DEM coverages are Level 1 DEMs even though not all were developed with the manual profiling technique. Therefore, the limitations of the DEMs discussed here generally apply to those coverages developed from manual profiling of photogrammetric stereomodels and for low relief topographic conditions similar to those encountered in this investigation. Other Level 1 DEM processing techniques, such as the Gestalt Photo Mapper II, have their own systematic errors within the stated accuracy standards, and these may also adversely affect drainage analyses.

Once the limitations of the DEM coverages were recognized, two alternatives were considered: editing the existing coverages or development of a custom DEM. The editing consists of either smoothing the coverage by using a box-car raster smoothing, or by applying a one by five custom raster filter perpendicular to the striping. Both alternatives would smooth out the striping, but were rejected because smoothing and filtering reduce the relief and the definition of the outline of drainage features. Retaining relief is critical for the definition of depressional wetlands which have little relief to begin with. Also, smoothing can introduce new drainage blockages at narrow passageways in the landscape, restricted valleys, and/or incised channels.

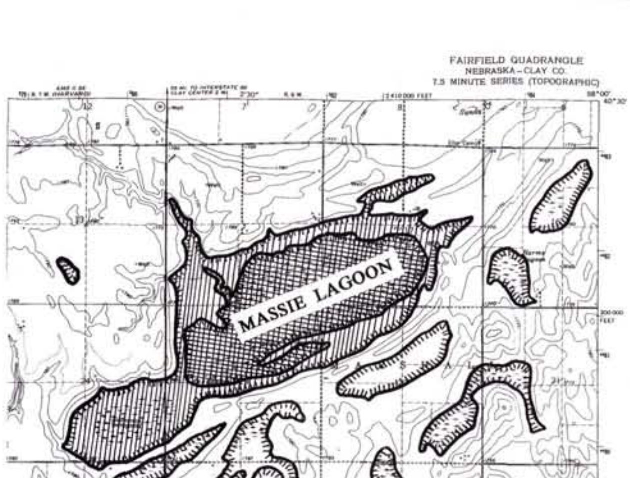

Figure 1. Northeast corner of the Fairfield Quadrangle; Massie Lagoon is highlighted by the hachured area.

Figure 2. DEM coverage of the Fairfield Quadrangle as displayed by a GIS.

The alternative selected by the authors is a custom DEM derived from the contours of USGS 7.5-minute topographic quadrangles. The contours of the wetlands and their contributing areas, including immediate surrounding areas, are digitized. The digitized contours are then interpolated into a raster DEM using a two-part algorithm. First, a search radius around the grid point is selected and those data points falling within that radius are assigned a weighting coefficient based on the distance from the grid point. Next, the grid point is assigned a DEM value which is the weighted sum of the data points divided by the sum of the weighting coefficients. In order to ensure accurate depressional analysis, a small search radius must be chosen to eliminate the influence of outlying data points. However, a small search radius often necessitates the addition of supplementary contours in areas where contours are few and far between. The result of this DEM production is shown in Figure 4 for the Massie Lagoon. The outline of the wetland, as well as the other neighboring wetlands, is well reproduced and conforms closely to the depression boundaries defined by the contours on the USGS 7.5-minute topographic quadrangles (Figure 1).

Summary and Conclusions

The limited application potential of certain USGS Level 1 7.5-minute DEM coverages for drainage analyses is presented. The Level 1 DEMs considered in this study were produced by manual profiling from photogrammetric stereomodels of National High-Altitude Photography. The geographic area for the investigation is situated in Clay County, south central Nebraska. The evaluation of 12 contiguous DEMs showed systematic and identifiable scan striping. The striping distorted the outlines of drainage features, biased the flow paths, and introduced apparent blockage of flow. The source of the striping was related to the manual profiling technique. The resulting anomalies were found to be within the USGS stated accuracy standards for Level 1 DEMs. Subsequent manipulation of the DEM coverages to remove the striping by smoothing and filtering were rejected because of the additional data degradation that they would introduce. A custom DEM, interpolated from digitized contours, proved adequate to conduct the drainage and wetland analysis.

The unsuccessful application of the USGS Level 1 7.5-

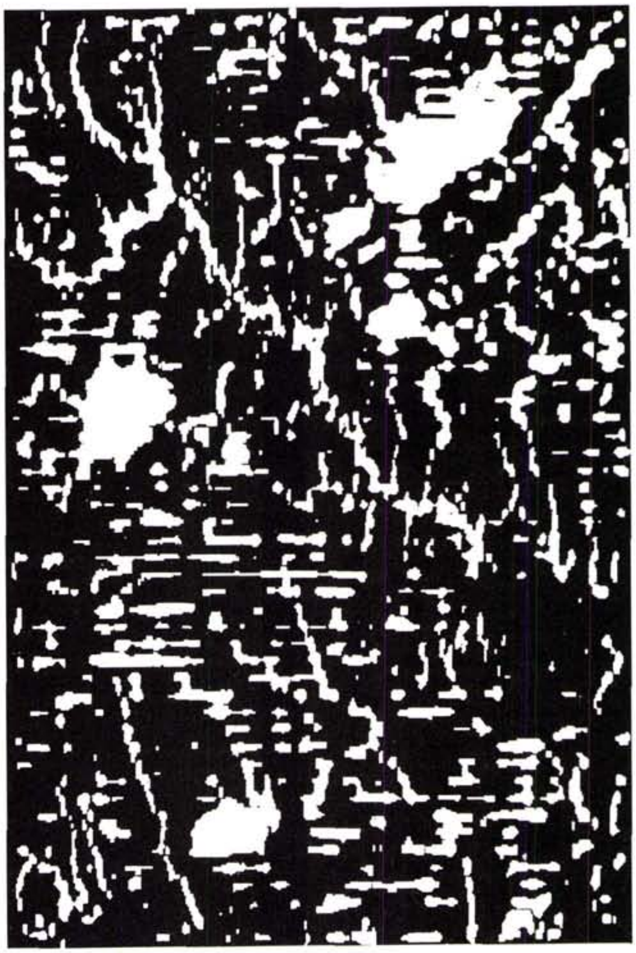

Figure 3. Location and extent of depression in the Fairfield DEM coverage; depressions are defined by the white areas.

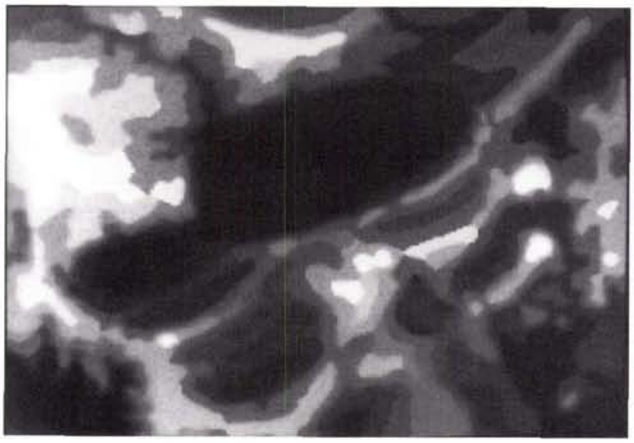

Figure 4. Custom DEM of the geographic area encompassing the Massie Lagoon.

minute DEM coverages produced by manual profiling is attributed to the requirement of a high DEM resolution and consistency for drainage analyses. The systematic errors encountered in the Level 1 DEM coverages are too large for the proposed drainage analysis even though they are within the stated accuracy standards set forth by the USGS. Therefore, caution is advised: the availability of USGS Level 1 7.5-minute DEM coverages does not necessarily guarantee a data source for a landscape analysis of drainage features. More detailed or higher resolution digital elevation data may be necessary.

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