Buffering-map overlay, interpolation-Digital Elevation Model-output data-devices for output

INTRODUCTION

Digital Elevation Models (DEMs) in its most generic term implies elevation of the terrain devoid of vegetation and manmade features. It represents the elevation of the earth's surface in the form of a digital image where each pixel1 contains an elevation value of the center point of the pixel

DEMs are a primary input to any modeling or process quantification involving the earth's topography, and are used across several areas of development. For instance, in water resources management, the earth's surface determines water flow; hence, there is intrinsic dependence on accurate elevation or topographical information typically represented as elevation map layers. In disaster risk management, disaster risks related to floods, coastal erosion, storm and/or tidal surges are directly linked to elevation. Access to elevation, and slope maps enable responders to assess where floods will infill the landscape, create inaccessible areas, or create health risks, e.g., cholera. DEMs are also used prominently in infrastructure planning and mapping; road design and construction for transportation; urban environmental planning to assess construction, drainage and green landscaping; agriculture planting and irrigation strategies; ecological modeling to assess ecosystem flora and fauna; and geological applications such as seismic and coastal monitoring

Accurate elevation information is therefore key for a wide range of development projects related to poverty reduction, urban development, water management and other concerns. Thus, the ability to design and commission or acquire DEMs is increasing in relevance across the globe. The primary target audiences of this DEMs Guidance Note are World Bank Group Task Team Leaders (TTLs), project managers and their clients, or anyone interested in DEMs. It primarily aims to: (a) provide sufficient information to understand the overall processes involved in the acquisition of DEMs and their uses, and (b) to inform and guide the decision-making criteria; different design and implementation strategies; and options and costs that exist when acquiring DEMs. This information and guidance can then help facilitate the most targeted, efficient, meaningful, and economic decisions for DEM acquisition that can be made contextually by both decision makers and implementers. As this document demonstrates, Digital Elevation Models is a highly technical topic, thus it is recommended that Task Team Leaders consult or hire a specialist before embarking on projects that require DEM.

DEM Applications

This Note includes an extensive list of applications for a DEM, in topics such as water resources management, disaster risk management, geology, agriculture and several others (See Section I-2: DEMs Applications). When drafting a proposal for DEM creation, it is often useful to state other potential uses of DEMs in the proposal rather than only the intended one; in this way the potential return on investment (ROI) is clearer to the funder. The ROI's maximum realization potential is achieved if the license of the generated DEM is made open. The DEM's usage greatly determines the DEM output's technical specifications. For example, for the modeling of coastal erosion, the DEM must meet the optimal specification (spec) requirements for the coastal erosion modeling methodology. Several options may exist to produce a DEM that fulfills the required spec for the project. In these cases, it is necessary for the project bidder to describe in the technical proposal the detailed methodologies envisaged to create the output DEM. DEMs can be created for terrains (land surface) as well as underwater (e.g. seabeds). Underwater DEMs are called Bathymetry, and their generation require a different approach and use of instruments compared to terrestrial DEM. For underwater, acquisition methods are different depending on whether near-shore or off-shore bathymetry is required, the threshold typically being water depth of 50m where beyond that sonar equipment are used. The costs of bathymetry data acquisition and generation is generally speaking 4–5 times more than that of terrestrial DEMs.

Modalities of DEM Generation DEMs need to be extensive and exhaustive in spatial scope using remote sensing, to be truly useful. Remote sensing, from an airborne (e.g., aircraft or drone) or a spaceborne platform (e.g., satellites), represents one of the best approaches for the development of large area, high-spatial resolution DEMs. The diversity of remote sensing modalities used to generate DEM products presents a breadth of choices, each with their relative strengths and weaknesses and different types of output. The objectives, scope, geographical location and budget of each project will determine which of the remote sensing approaches are most appropriate to the task. Section II-1: Operational Guide to Tender a Digital Elevation Model, discusses the different DEMs' modalities, and Section II-2: Workflow to Acquire a DEM for Projects, describes five key steps to acquire a DEM for projects. Three remote sensing technologies provide elevation data: Light Detection and Ranging (Lidar) is more automated and finely scaled; Radio Detection and Ranging (Radar) is more effective in foggy or cloudy conditions. Stereo photography (three-dimensional imaging), however, only collects ground elevation data for physically observed or imaged areas. Lidar offers dense 3D point clouds, vegetation-penetrating abilities, and multiple secondary applications. Radar also offers vegetation penetration, but lower spatial resolution and higher processing needs. This can result in lower quality and increased cost in some circumstances/situations. Stereo photography offers context through imagery, but offers lower spatial resolution and only top-most surface heights. Spaceborne platforms offer accessibility and coverage, but at the cost of spatial resolution and horizontal and vertical accuracy, making them especially useful for large areas (e.g., regional-to-continental mapping). In contrast, airborne platforms have much higher accuracy but sacrifice coverage and accessibility in very remote areas. Multiple variables also define the output quality and characteristics of a DEM. The most commonly quoted variables are the vertical accuracy and horizontal point spacing (resolution). For vertical accuracy, photogrammetric or Lidar systems are best for higher vertical resolution applications in the order of less than 1m. Medium or lower accuracy applications allow the use of Interferometric Synthetic Aperture Radar (IfSAR), in the order of 1m to 5m, and satellite archive data. Section II-3: Requirements and Options includes Table 9: Key accuracy requirements for a range of application areas, which shows the required DEM vertical accuracy for various applications. Section II-3.3.vii: Budget Constraints, includes Table 10: DEM product costs for various remote sensing modalities and vendors, which shows some examples of DEM product types (some being commercial-offthe-shelf (COTS) products), their vertical accuracy, and the approximate price range and licensing conditions. It is worth mentioning that there are global COTS DEM products available at either no charge2 or at cost.3 However, in most instances DEM applications in topics such as water resource management, disaster preparedness, or agriculture generally require a finer spatial resolution than what best global products can provide. The objectives, scope, geographical location and budget of each project will determine which of the remote sensing approaches are most appropriate to the task. Section II-3 and 4: Sustainability Matrix and Applications Requirements Matrix discusses the various modalities of DEM generation.

Generating DEMs and the Terms of References (ToRs) A given project could also use certain key attributes to define DEM products and to generate a ToR, (also referred to as a Statement of Work (SoW)), and a Request for Proposal (RFP) for product vendors. Section III-1: Key Attributes for DEMs and the Annexes provide a list of the 15 attributes discussed herein.

This Note also provides the key decisions and many considerations needed to plan a Lidar survey, based on the intended use of the DEM when commissioning such instrument. One such decision is whether the output DEM 2 For example, Shuttle Radar Topography Mission (SRTM) http://www2.jpl.nasa.gov/srtm/ 3 WorldDEMTM http://www.astrium-geo.com/worlddem/ x Executive Summary will include/exclude the non-Earth surface vertical information (i.e., buildings or vegetation) depending upon the desired information. There are three different types of digital surface data: DEM, Digital Terrain Models (DTM), and Digital Surface Models (DSM). Section III-1B: Digital Surface Data Types, describes these further. Another consideration during the undertaking of a Lidar survey is whether to acquire aerial photographs concurrently, given that it is a common and cost-effective practice. Regardless of how the DEM is created, it is recommended that a specialist be involved in the drafting of the ToR, especially if the preferred modality is Lidar. A Lidar specialist should be fundamental to the team to ensure that the ToR incorporates and specifies all variables. The specialist would also evaluate the proposals to ascertain there are no pitfalls or gaps in the technical components of the selected bid, which may not be as transparent or simple to the untrained eye. When a Lidar aerial survey is to be executed, there are standard documents and reports that are expected to be submitted by the vendor prior, during, and post-flight, to ensure data quality. Section III-2E: Deliverables, discusses a project's expected deliverables from a vendor. The requirements for the output DEM—such as the resolution, accuracy, deliverables, and cost implications— are different from project to project, depending on the envisaged usage of the DEM. It is important to clarify the intended use of the DEM before commissioning the work to identify the optimal DEM specs. The ToR or SoW communicates these specs. The ToR serves as the common point of reference between the project manager and the vendor. It requires careful specification by the project manager, as a vendor is only responsible for what is contained in the ToR and the technical and financial proposal. If the project manager should decide to alter or add to the vendor's requirements after a ToR agreement is established, there is significant risk of a price increase or slip-up in schedule. Section III-4: DEM Acquisition Terms of Reference, discusses the ToR's technical specifications requirement(s) to generate a DEM. ToR and licensing agreement examples are provided in the Annexes. It is also important to consider data storage and sharing plans as part of the implementation plan. The data will be wasted unless it is stored and technically made useable by end users.