GIS for National Mapping

An Esri® White Paper
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Introduction

This technical paper is intended for managers and staff of national mapping organizations (NMOs). This includes any country, state, province, region, or devolved area that has official mapping responsibilities.

Scope

This paper is intended to explain the vision, benefits, technologies, workflows, and best practices for deployment of Esri's ArcGIS® geographic information system (GIS) solutions to solve the business requirements of NMOs. It wiil also be of interest to related organizations such as cadastral, hydrographic, aeronautical, and environmental agencies, but Esri also publishes papers covering these markets more specifically.

The main section provides a task-oriented overview of the Esri® ArcGIS system benefits, arranged in the natural work sequence of a typical NMO. Appendix 1 covers workflow and quality measures, and appendix 2 covers relevant standards and data models. Appendix 3 summarizes where to find further information.

NMOs

Almost every nation or autonomous region has one or more official organizations dedicated to topographic and administrative mapping. These national mapping organizations produce a range of digital products and services as well as the more traditional series of paper maps, charts, and plans. For some nations, the NMOs also generate defense mapping/geospatial intelligence, aeronautical or nautical charting, or geologic mapping or cadastral records; for other nations, these are the responsibility of separate agencies.

NMOs operate at the heart of their nations' geographic information infrastructures and are leaders in the delivery of authoritative, nationally consistent products and services that support good governance, private business, education, and the individual consumer. As such, NMOs meet many diverse needs such as e-government, emergency management, safety at sea and in the air, national and regional planning, infrastructure management, geomarketing, and telecommunications.

Challenges and Opportunities

While the demands from users have increased and diversified, so too have the pressures on NMOs to operate more efficiently and effectively. Today, NMOs are expected to generate more and better products and services in less time and with fewer resources, all while improving customer satisfaction and building new business partnerships.

For today's NMOs, this new reality requires the continuous development of staff skill sets and the modernization of technology and workflows in an agile, scalable architecture that will support both today's and tomorrow's needs for mapping, charting, and land administration. Esri is the world's major provider of GIS solutions. Its ArcGIS software system offers powerful, database-driven cartographic and geodata production capabilities that enable users to produce their mapping products from large, multipurpose geographic databases rather than having to manage disparate datasets for individual products. This complete system approach improves the quality and consistency of products while driving down production costs.

Spatial Data Infrastructure

Nations have a clear need for accurate framework data in a spatial data infrastructure (SDI) to support good governance. This data must be shared throughout government and externally through data-sharing portals. In some regions, centrally mandated requirements for data sharing are invoked, such as the Infrastructure for Spatial Information in Europe (INSPIRE) Directive. NMOs play a key role in building and disseminating core components of the SDI while minimizing data redundancy and

avoiding duplication of tasks. ArcGIS is based on key interoperability and web computing concepts and is used by tens of thousands of organizations that rely on GIS and information technology interoperability to collect, manage, produce, and share geospatial information. Later sections of this document show how those capabilities can help NMOs meet the SDI vision.

Vision for NMOs

To meet these evolving requirements, NMOs are moving from the separate silos of traditional map production workflows to a modern, multipurpose workflow based on a central database offering a range of products and services: "capture once, use many times." The GIS-based approach pioneered by Esri and described in this document has revolutionized mapping and map production. ArcGIS supports the complete production workflow implemented by NMOs, including task management, source data capture, imagery assimilation, data management, quality control, data editing, cartographic production, and product dissemination including web services. The following sections of this document are organized in the typical workflow of collecting, managing, producing, and sharing to meet this vision.

Customers' expectations are being influenced by the rapidly changing world of information technology (IT) and the Internet. NMOs therefore must deliver their information through web and mobile environments as well as continue the use of desktop and server technology. The advent of cloud-based application servers opens up massive and adaptive scalability of online map and geospatial services, providing new, efficient routes to market for NMOs. ArcGIS is cloud-ready and can be scaled from the desktop through in-house servers to the cloud as needed.

ArcGIS

The primary Esri product for NMOs is ArcGIS. This is an integrated system of GIS software that provides a standards-based platform for spatial analysis, data management, and mapping. ArcGIS is scalable and can be integrated with other enterprise systems. It is built from a common software code base and hence provides a uniform experience and compatible functionality across desktop, server, mobile, and embedded implementations.

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Esri Approach

A spatial database—the geodatabase—lies at the heart of the Esri approach.

Database-Centered Workflow

In the past, a typical NMO had disparate linear flowlines with separate datasets for each of its products and services. In the new world of GIS-based mapping and land administration, the four main NMO tasks to collect, manage, produce, and share all act on the live data in the central shared geodatabase in a unified transactional workflow, as described in the following figure.
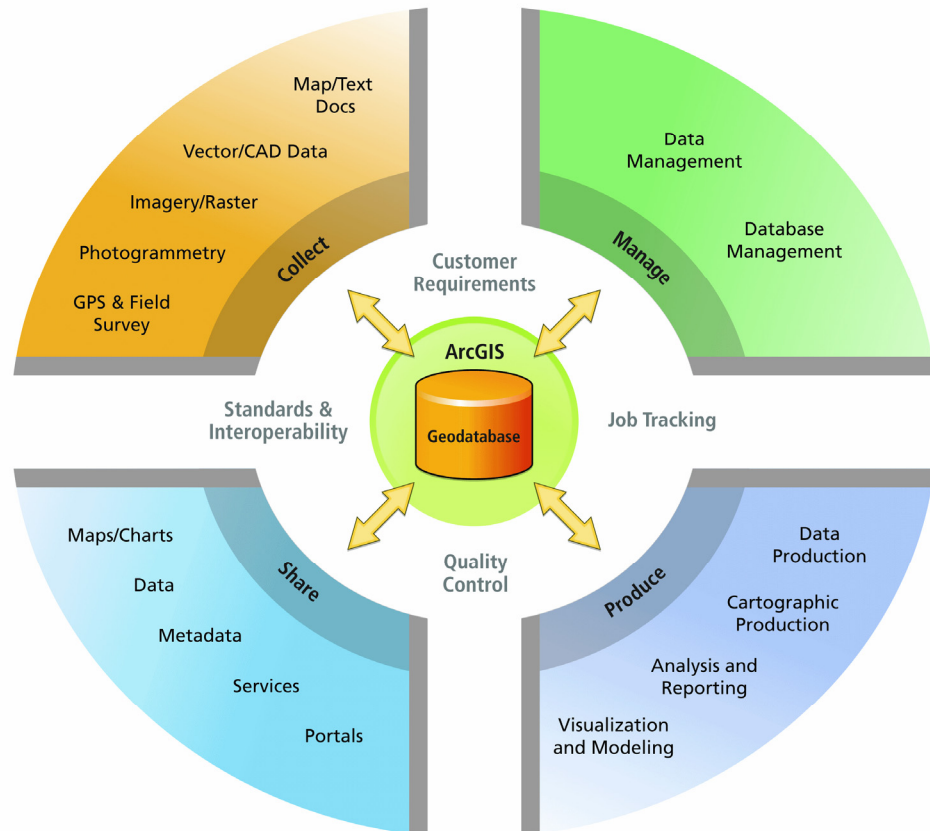
Figure 1—The Transactional Workflow Quadrants

Collect

The **Collect** quadrant is primarily responsible for gathering and updating the master geography: the digital landscape model, or DLM.

Manage

The **Manage** quadrant builds and maintains the data schema, handles changes through time, coordinates multiuser access, and improves and enforces data quality.

Produce

The **Produce** quadrant is where cartographic design and map authoring tasks take place. This includes the creation of cartographic representation rules and overrides and the generation of labels and layouts. Along with analysis, modeling, and generalization to create derived data, these generate the digital cartographic model, or DCM. Web maps will often involve authoring multiscale mapping, a coherent set of maps with consistent style across a range of scales. Also in this quadrant are analysis and reporting processes.

Share

The **Share** quadrant includes the outward-facing aspects of providing standard and on-demand maps, spatial information products, and web services to customers and business

partners. Paper products are still important but, increasingly, the communication is to applications on mobile devices, such as smartphones, as well as web mapping and soft-copy downloads to tablets and portable computers. It also includes metadata, search, portal, and data-delivery technologies that can position the NMO at the heart of a National Spatial Data Infrastructure (NSDI).

Collect
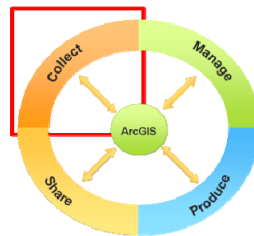
The Collect quadrant of the workflow includes compiling information from field surveys, Global Navigation Satellite System (GNSS)/GPS, maps, imagery, photogrammetric surveys, lidar point clouds, CAD data, and existing digital data to build a digital landscape model.

Field Survey

The fundamental information that NMOs must capture and maintain is the position of real-world objects. Remote sensing and photogrammetry are very relevant sources (covered below), but in many cases, there is no substitute for a surveyor visiting the location and observing and recording reality firsthand.

Equipment used for a field survey may be PDAs running ArcPad®; palmtops running ArcGIS for Windows Mobile; ruggedized handhelds running ArcGIS Engine applications; or, increasingly, smartphone or tablet applications using mobile APIs running ArcGIS for iOS (iPhone or iPad) or Android operating systems. Surveying usually involves determining absolute positions (often from GPS) or relative positioning (from laser range finders, etc.) and recording the data directly into the GIS.

Back in the office, ArcGIS for Desktop Standard and Advanced (formerly ArcEditor™ and ArcInfo® license levels) contain coordinate geometry (COGO) tools optimized for input of survey measurements in the form of distances and angles.

GPS Survey

Modern survey techniques make much use of GNSS technology, typified by the Global Positioning System, which allows a surveyor to determine locations (longitude, latitude, and altitude) to within a few meters using time signals transmitted by radio from satellites. Positioning can get to decimeter accuracy when GPS observations are corrected by reference to a local base station. GPS is being supplemented by the Russian GLONASS, Chinese COMPASS, and European Union's Galileo GNSS systems. Esri data collection software (ArcGIS for Desktop, ArcGIS Engine, ArcGIS for Windows Mobile, and ArcPad) can all take direct feeds from GNSS devices to capture positions for collection or update of features.

Map Scan and Vectorize

Most NMOs have legacy paper map documents containing useful historical information that needs capturing into versatile vector form. ArcGIS provides raster vectorization and editing, allowing the capture and exploitation of legacy paper mapping.

Imagery

Remotely sensed imagery, whether from aerial photography or satellite sensors, is a primary and increasing asset for NMOs. It is used in pictorial form as a backdrop to operations, particularly for building and maintaining the central vector database. Imagery forms a base on which features can be quickly interpreted, in either 2D, from orthoimagery, or 3D, from stereo imagery. Increasingly, image analysis and automated feature extraction from multispectral imagery are used to improve productivity. Imagery is usually available over multiple years and hence provides the basis for much temporal

analysis. ArcGIS can store imagery in the geodatabase or can process, mosaic, and serve imagery on the fly directly from the original data files.

Photogrammetry

Aerial photography in raster form is a valuable source of information for NMOs, but photogrammetric capabilities are needed to reconstruct the vector geometric form of real-world objects from the imagery. Photogrammetry accurately orients images prior to the creation of stereo pairs that reconstruct the world in three dimensions. These stereo pairs are then used in stereo-image workstations to extract vector coordinates (planimetric or 3D). Along with elevation models, the oriented imagery is used to create orthoimagery from which planimetric features are often extracted. Esri has the capability to generate and serve orthoimagery and works closely with a number of partners that provide specialized hardware and software for photogrammetry that are closely integrated into the ArcGIS framework.

CAD Data

Many surveyors have traditionally used computer-aided design software for survey data capture and cleaning. CAD is also prevalent in engineering disciplines, such as road infrastructure, that are often closely coupled with NMOs. The ArcGIS for AutoCAD extension lets CAD users directly access GIS mapping and data, while ArcGIS can directly read and load CAD formats such as DWG or DXF. This preserves NMOs' investments in CAD technology but also facilitates moving the workflow onto GIS.

Extract, Transform, and Load

Existing digital data in legacy or third-party systems often needs to be moved or copied into the master spatial database of an NMO. ArcGIS provides tools in ArcCatalog™ and in the geoprocessing framework for importing external data, including simple schema changes. However, there are superior capabilities in the ArcGIS Data Interoperability extension that can read and write many dozens of formats. This includes a powerful visual workbench with a drag-and-drop interface that can carry out sophisticated schema transformation and data selection tasks as part of the loading process.

Lidar and Point Clouds

Lidar is high-accuracy, high-resolution elevation data, often derived from airborne sources. A laser beam is used to measure the distance between aircraft and the ground, including ground features such as buildings or trees. The result of processed lidar scanning is usually a point cloud—a very large number (many millions) of 3D (x,y,z) points. ArcGIS and the geodatabase can store and access this kind of data, and the 3D Analyst™ extension aids NMOs in visualizing and exploiting such point cloud data.

Manage
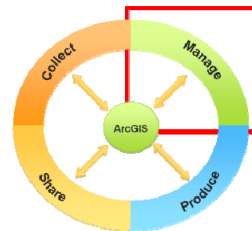
This quadrant of the workflow builds and maintains the database and data schema, handles changes through time, and improves and enforces data quality. It synchronizes the work of multiple users, interweaving their transactions while avoiding and resolving conflicts. The key components to managing data in an NMO include the following:

Geodatabase

There has been a major push from mapping organizations to centralize their data holdings to avoid the fragmentation and inefficiencies of file- and sheet-based data held by departments and individuals. Related to this is the ongoing pressure to move GIS and cartography into the world of enterprise information technology and take advantage of commodity facilities for backup and data replication and management.

Esri has recognized this need and provided the enterprise geodatabase as the central repository for spatial data, handling continuous data without tile edges in an open

relational database such as DB2®, Oracle®, Informix®, SQL Server™, or PostgreSQL. The use of commodity database technology allows the close integration of spatial data with other business data vital to the enterprise, and it facilitates the production of a wide range of valuable analytical and cartographic products.

Vector Features

The key data in the geodatabase is held in feature classes of vector features. These hold spatial information as geometry (point, line, or area) together with attributes describing the feature. Typical classes for NMOs include parcels, buildings, roads, and rivers. Each feature class is held in the geodatabase in a single relational table.

Relationships

Relationship classes can be used to combine and link features in different classes (e.g., a building that has postal access from a given road). However, many relationships can be deduced spatially and dynamically by the GIS and do not need to be stored, ensuring consistency and simplifying maintenance.

Raster Data

While vector data is used for discrete objects, there are other geographic phenomena important to NMOs that are more continuous. These are modeled as grid, matrix, or raster data and include imagery (aerial photography or satellite sensed), terrain elevation, or slope models or the results of thematic analyses. The geodatabase has a rich set of raster storage and retrieval modes suitable for different resolutions and types of such data.

Lidar and Terrains

Of increasing importance to NMOs are the 3D datasets arising from sensing the real world using aerial or terrestrial lidar. These may have many millions of x,y,z points. The geodatabase has optimized data types for holding lidar and also for the triangular irregular networks (TINs) that are often created from such data to model ground surfaces.

3D Volumes and City Models

The geodatabase has specific multipatch data types for holding 3D volume data, such as those describing buildings using sets of triangles, faces, and textures.

Networks

Many man-made (e.g., roads) and natural (e.g., rivers) features link to form networks. The geodatabase provides structures for storing and building such networks together with attributes (such as banned turns for roads or flow directions for rivers).

Fabrics

Particularly relevant to NMOs are the different kinds of polygons covering the whole land. These include cadastral parcels (landownership), land cover (grass, trees, concrete), and land use (agriculture, sport, transport). The geodatabase provides specific capabilities for storing and building such uniform polygon coverages and, particularly in the case of cadastral parcels, retaining the underlying survey data in a parcel fabric.

Schema

The data model or schema is the empty template into which the actual data instances are loaded. It defines the feature classes and their names, geometric types, attribute fields, and relationships. The ArcCatalog facilities of ArcGIS are used for creating and maintaining data schemas, complemented by a set of automation capabilities implemented as geoprocessing tools within the ModelBuilder™ automation framework. Esri also provides preprepared template schemas for particular markets, as described in appendix 2—Data Models and Templates.

Quality and Integrity

Bad data can be worse than no data. NMOs are subject to legal and administrative requirements to assess and enforce data quality as well as performance costs if poor quality impedes later use. Through its common source code and rigorous geodatabase models, the ArcGIS environment provides a consistent approach to data quality and integrity checking and enforcement. It provides geoprocessing tools for checking geometries for common errors (e.g., the figure of eight polygons, slivers, overlaps) and

cleaning and merging disparate datasets (Integrate tool). The schema supports attribute domains to ensure that only valid values are stored.

In addition to the core data integrity capabilities of ArcGIS, the ArcGIS Data Reviewer extension focuses on data quality control/quality assurance (QA/QC). It provides QA/QC tools for interactive and automated quality checks to verify compliance with user-defined rules. It is described further in appendix 1.

Structure and Topology

The raw linework from survey, CAD, or legacy mapping often contains geometry overshoots, gaps, slivers, and overlaps. ArcGIS has a powerful, rule-based topology engine that can take this data, clean it, and build it into structured networks and continuous polygon tessellations. This functionality is vital to NMOs in eliminating errors resulting from overlapping boundaries and incomplete polygon descriptions and for building clean road networks and land-use coverages. In addition, interactive topology editing tools in ArcGIS speed up polygon editing and safeguard the continued integrity of the data. Similar topology and data integration capabilities are also important in maintaining the consistency of the various layers of GIS data, ensuring that the various levels of administrative boundaries all nest cleanly within one another and match the fences or roads where they should be coincident.

Parcel Fabric

Some NMOs have cadastral responsibilities that involve creating and managing a parcel fabric (sometimes called a cadastral fabric), a contiguous set of parcel polygons across a whole country or region. Parcels are the foundation of vital spatial infrastructure such as landownership registers, land-use or land-cover datasets, or property taxation records. To help an NMO build and maintain such a fabric, ArcGIS provides tools including ones for that important task of adjusting multiple adjacent surveys to fit together cleanly.

Versions and Transactions

The world is constantly changing, and NMOs have to continuously update their data and maps to keep up. The data stored in the geodatabase can be versioned to allow multiple users to carry out simultaneous updates with optimistic long transactions to prevent unnecessary locking or data copies. Versioning is particularly important to provide a stable view of the data during cartographic product generation and map finishing, enabling the meeting of fixed deadlines for publishing while allowing others to continue in parallel with ongoing database updates. For cadastral mapping, versioning handles the all-or-nothing nature of land transactions, ensuring that a consistent state is always visible without conflicts. Versioning also allows NMOs to supply tailored versions of the data to meet different user requirements.

The enterprise geodatabase supports sophisticated reconcile and post capabilities to handle the merging of changes from multiple users, including ones to combine edits done by two operators to the same feature.

History and Archiving

Although most customers of NMOs are interested in seeing up-to-date mapping, there are important legal and procedural reasons why it can be important to be able to look back in time. ArcGIS therefore has versatile capabilities for history management and archiving. While versions are of limited duration and must be regularly merged or deleted, archive tables are permanent and provide a traversable history of the changes to features. This allows the user to wind back in time and see what the geographic features in an area previously looked like.

Replication

Some NMOs are concentrated in single locations in their countries, but others are spread across a number of district and/or regional offices. The "differences" technology in the

geodatabase used for versioning also underpins replication solutions to manage large-scale GIS deployment across multiple sites. Just the changes are transmitted as XML-based messages to support master-subordinate replication or peer-to-peer synchronization.

Backup/Recovery

All NMOs are absolutely reliant on their core geographic data, and it is vital that this is preserved in case of hardware or software failure or in the event of accidental or malicious damage. ArcGIS and its underlying database technology provide a variety of backup capabilities, from full database copies to incremental saves (changes-only) to data subset exports. Such backups can then be restored to ensure that the enterprise is back to full function in minimum time.

Scalability

The geodatabase that is at the heart of the Esri approach is enormously scalable:

■ At the lower end, a file geodatabase can store the data for a small project or a field-worker.

■ The next step up is the workgroup geodatabase. Stored in SQL Server Express, it can share access with multiple writers.

■ Next is the enterprise geodatabase stored in Oracle, DB2, Informix, SQL Server, or PostgreSQL. It can handle thousands of readers and hundreds of writers simultaneously.

■ Finally, there is scalability into the cloud—Esri supports cloud computing from multiple providers including Amazon's Elastic Compute Cloud (EC2) and Microsoft Azure for running ArcGIS for Server applications.

Produce

This quadrant of the workflow is where the data is processed and analyzed, where value is added by distilling data to give useful information, and where mapping and geodata products are generated.

Cartography and Map Production

Taking raw geospatial data and processing it to produce useable maps, charts, and plans is a primary role of NMOs. A complete cartographic production system is available within the Esri ArcGIS system. Cartographic design and map authoring are the starting points for this task, followed by map editing and finishing.

Cartographic Representations

ArcGIS provides the ability to create multiple cartographic representations for individual features. This includes cartographic representation rules, storage of multiple representations in the geodatabase, and their overriding for cartographic freedom while deploying the database's ability to model, share, and automate updates.

The representation rules allow automated visualization to meet demanding cartographic clarity standards, while overrides stored in the geodatabase provide for exceptions generated from the GIS features by either automated procedures or manual intervention. Representation rules provide the cartographer with the freedom to modify the strict rules of the GIS symbology just where it's necessary, hence producing the required visual

quality expected of NMOs without affecting or unnecessarily copying the underlying master data.

Priorities, Masking, and Transparency

In addition to the representation of individual features, it is necessary to control the visual interactions between features to produce a clear map. ArcGIS supports masking (where one feature can suppress the drawing of another), symbol-level prioritized drawing (where the drawing order of road casings and fills can be controlled to give clear road intersections), and transparency (where features can be seen through other features).

Text, Labels, and Annotation

All maps, charts, and plans include text for names of places and geographic entities. ArcGIS provides intelligent dynamic label placement and can store generated text in the database as annotations, which can be freestanding or feature linked. Feature-linked annotations are tied back to the GIS feature from which they were created so that they can be automatically updated. The acclaimed Maplex® labeling engine is integrated into ArcGIS and can automate the previously labor-intensive task of labeling maps, producing consistent, high-quality results with minimal human intervention. Many users report a ten-fold increase in productivity compared with previous manual methods of text placement. At ArcGIS 10.1, the capabilities of the Maplex extension are included as core functionality in all levels of ArcGIS.

Layouts

As well as data mode, for maintaining the continuous master datasets, ArcGIS has layout mode, for defining and manipulating the page, sheet, or screen layout for visual products. Layouts can contain multiple map frames, each with selectable content at specified scales and presented with particular symbology. They may also contain multiple layout elements: title, legend, north arrow, descriptive text panel, logo, and so forth. These layout capabilities provide the NMO with the facilities to generate rich map products that are ready for printing without the need for a separate imposition system.

Sheet Series and Atlases

ArcGIS 10 introduced Data Driven Pages, which allow NMOs to quickly and easily create a map book or series. This generates a series of layout pages from a single template map. An index layer divides the map data into sections and generates one page per index feature. Data Driven Pages can be based on a regular grid of polygons or on irregular shapes. In addition, there are new capabilities for dynamic text in the layout and for scripting in the Python language. These all combine to greatly reduce the effort in producing cartographic product series.

Export and Prepress

The ArcGIS map export capabilities allow NMOs to do the following:

■   Send map layouts directly to a variety of printers for both proof plotting and printing on demand

■   Create color separates for use with high-resolution film recorders, digital platemakers, and digital printing presses

■   Transfer maps to graphics packages such as Adobe Illustrator®, for embedding in other documents

■   Output maps into digital visual formats, such as PDF, and a wide variety of image formats (ArcGIS supports GIF, PNG, TIFF, and JPEG image formats and EPS, Adobe Illustrator, and SVG vector formats.)

The major format now for cartographic production is Adobe Acrobat® PDF, which has become the preferred format for prepress operation and web publishing.

Data Products

For most NMOs, the amount of product supplied as data (vector datasets and raster coverages) has risen through the years to exceed that supplied in visual form (paper maps and map images).

Vector Data Products

A vector data product is rarely just a dump of the master data from the primary database. The public data model is often different from the internal model, as it is optimized for customer use rather than the NMO's repository. Processes of data selection, schema simplification, attribute reclassification, and geometry clipping may need to be carried out. These can be done on the fly as part of the preparation for individual shipment, or there may be distinct product datasets created for standard products that will be shipped to multiple customers. ArcGIS contains a wealth of capabilities for such selection and transformation, including data synchronization to one or more subordinate product databases, optimized for data distribution.

International Products

ArcGIS can handle the requirements of NMOs for local languages, character sets, and fonts. ArcGIS supports the Unicode standard, which allows the use and mixing of characters of the major writing systems of the world.

Increasingly, NMOs are becoming involved in supranational projects, where products have to meet standard international specifications. Examples include EuroRegionalMap and the Multinational Geospatial Co-Production Program (MGCP). See appendix 2 on data models for more information.

Imagery Products

ArcGIS has a range of raster and image processing capabilities that allow NMOs to generate raster products as both visual backdrops and the results of analysis. In addition, aerial photography and remotely sensed imagery can be dynamically processed and served through the ArcGIS Image extension.

Generalization

The strategic goal of most NMOs is to capture the real world once and use it to generate diverse products at multiple scales. Generalization is the process that takes detailed, high-resolution, large-scale master data and derives simpler, clearer subsets for use in smaller-scale products.

Historically, generalization was a single-step process done by a human cartographer as part of the compilation of a particular map product from the available sources. Now, it is often useful to think of generalization as a two-step process—model generalization, which reduces data volumes, and cartographic generalization, which improves clarity.

Model Generalization

Model generalization (sometimes known as database generalization) involves the processes of selection, reclassification, simplification, and aggregation. Its purpose is to reduce data volume and complexity to a level appropriate for the planned use. ArcGIS provides a rich set of geoprocessing tools that, using ModelBuilder, can be combined into geoprocessing models that can carry out such automated generalization. Specific tools are available in the generalization toolbox for feature simplification and aggregation.

Cartographic Generalization

Once the data is at the appropriate resolution and unnecessary features and vertices have been discarded, cartographic generalization is needed to present the database data in visual form with sufficient clarity to communicate the required message. Cartographic generalization may include some of the same processes as model generalization but, in addition, often includes feature exaggeration, displacement, and typification. Again, ArcGIS geoprocessing tools include ones specifically for the detection and elimination of cartographic conflicts. Exciting new contextual generalization tools for displacement and thinning of roads and buildings have been added, which makes use of a powerful new optimization engine to balance the often-conflicting constraints.

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Analysis and Reporting

One of the main strengths of GIS is its ability to combine, analyze, and report spatial data and relationships. ArcGIS software's rich set of geoprocessing tools is now important to NMOs as they maximize the derived value of their data holdings.

Analytical Processing

Analysis by an NMO usually starts with the geoprocessing of existing data to make explicit some of the implicit relationships hidden in the spatial data. ArcGIS provides a rich geoprocessing framework and the associated visual ModelBuilder application to facilitate the analysis of spatial data. In the geoprocessing toolboxes is a wealth of tools for the combination, selection, and analysis of data such as overlay operations, proximity analysis, frequency analysis, and statistics. These tools and models can carry out spatial production tasks such as deriving urban extents from building footprints or answering ad hoc questions such as, "Which town is nearest the center of the country?"

Scripting

In addition to use of the standard geoprocessing tools and ModelBuilder models, ArcGIS extends the scripting environment using the Python language, much used in scientific analyses and mainstream IT. This allows easy incorporation of organization- or industry-specific algorithms. Scripting also facilitates workflow automation, greatly decreasing operator time and increasing productivity.

3D Modeling

The work of NMOs is increasingly moving from being 2D (planimetric) to 3D (volumetric). The 3D Analyst extension provides three-dimensional visualization, topographic and intervisibility analysis, and surface creation. For NMOs, it allows creation and visualization of digital elevation models (DEMs) plus derived terrain datasets, such as slope and aspect, as well as impressive 3D city models.

3D Models

With 3D Analyst, NMOs can build and visualize 3D models of terrain surfaces or urban building landscapes. 3D Analyst also provides tools for three-dimensional modeling and analysis, such as viewshed and line-of-sight analysis, spot-height interpolation, profiling, steepest-path determination, and contouring. 3D is a fast-developing area, and modern 3D modeling standards such as CityGML and Collaborative Design Activity (COLLADA) are supported. Rule-based 3D representations of 2D data features can be done with Esri CityEngine tools.

Globes, Scenes, and Fly-throughs

Experience with 3D computer game software is raising the expectations of users (particularly younger ones). The two visualization applications of 3D Analyst (ArcGlobe™ and ArcScene™) make it easy to create realistic scenes in which people can navigate and interact with NMO data in a virtual, 3D world.

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Share

This quadrant of the workflow covers the outward-facing aspects of the NMO's role. This includes making available all map and data products and higher-level metadata and responding to user requests for geospatial and land information services.

Maps, Charts, and Plans

Although people have been predicting for decades that the days of the paper map are numbered, NMOs still have continuing and often new requirements to provide visual map products. Bulk printed maps, charts, and plans are still common, but the growth is in print-on-demand, downloadable documents (e.g., PDF) and web maps.

Topographic Maps

NMOs are the owners of the national topographic map series for most countries, usually at scales between 1:10,000 and 1:50,000. This basemap product (which often had its roots in military planning) is now vital for many aspects of planning at all levels of government and disaster and emergency coordination. It is also the most publicly recognizable product of NMOs; hence, its integrity and presentation quality are vital.

Esri has substantial experience in assisting NMOs in producing, maintaining, and modernizing topographic mapping, and the Esri Production Mapping extension is particularly relevant. See appendix 2—Data Models and Templates for more details on specific solutions.

Cadastral Maps

Cadastral plans are a primary product for those NMOs that have land administration responsibility. They are typically at much larger scales than topographic maps, often at 1:1,000 or larger scales for urban areas, and the number of sheets can be in the hundreds of thousands, making automation even more important. They show land parcels and often building extents plus other relevant detail. ArcGIS capabilities for Data Driven Pages are very applicable to automation of cadastral sheet production.

However, the large scale and local interest of cadastral maps are making web mapping solutions with on-demand printing increasingly the channel of choice for sharing cadastral mapping. ArcGIS for Server is the workhorse for such a service, providing web mapping to browser clients and, when the area of interest has been identified, producing a site-centered plan in PDF for local printing.

Navigation Charts

Navigation charts are usually the responsibility of separate charting agencies (often military), but sometimes are in scope for combined NMOs. These include hydrographic charts, used for ship navigation, and aeronautical charts, used for aircraft flights. Esri Nautical Solution and Esri Aeronautical Solution are particularly relevant. See appendix 2—Data Models and Templates for more on these solutions.

Print on Demand and PDF Download

For NMOs, there is a paradigm shift away from producing and stockpiling printed maps toward producing maps on demand. This allows the maps produced to be optimized for the particular use or task. ArcGIS for Server has all the map printing and export capabilities of ArcGIS for Desktop and is increasingly the channel for producing such on-demand mapping. The ubiquity of PDF as a page transfer format and the presence of Adobe Reader on almost all clients have also facilitated this approach.

Web Mapping

The provision of mapping to Internet web clients is not new to NMOs but is undergoing dramatic evolution of technology and the resultant user experience. In the past, web maps

were small images produced by an Internet map server and tended to be limited to simple visual appearance and slow and limited interaction. Panning to one side required redrawing the whole screen.

Now, the underlying technology is ArcGIS for Server, which can produce high-quality cartography and serve it at high speed across broadband links to intelligent clients. Cached tiled map services can reduce the time for panning operations to a second or less, as only the changes are sent from a preprepared cache. Because the tiles are preprepared, they can use the ArcGIS cartography for optimal map clarity without affecting the speed of display. For more volatile data, recent releases of ArcGIS for Server have introduced fast dynamic map services using a new purpose-built graphics engine.

Intelligent Maps

The richness and attractiveness of the web and mobile client applications have also improved dramatically, due largely to the introduction of new web graphics technologies such as Flex, JavaScript, or Silverlight. As a result, not only can web mapping now replace the use of paper maps for many users but also many practical applications run directly on the map, providing tailored end-user functionality.

Cloud

As an alternative or supplement to hosting their own web servers providing web mapping, NMOs can now take advantage of external servers in the cloud. These can be servers managed by Esri (as those in ArcGIS Online) or servers dedicated to and managed by the NMO.

ArcGIS Online

ArcGIS is now available online (esri.com/software/arcgis/arcgisonline/), providing useful basemaps, free programming APIs, and geoprocessing and query services. In addition, ArcGIS Online can host maps and data from organizations such as NMOs, making products readily available to many more users.

ArcGIS.com

The primary gateway to these online services is ArcGIS.com. The Esri community basemaps and targeted map services that are provided as part of the ArcGIS Online experience at ArcGIS.com are a good example of the scope of cloud GIS.

Cloud Servers

Esri also supports direct deployment of ArcGIS for Server into Amazon EC2 or Microsoft Azure, providing massive scalability of NMOs solutions as well as faster application deployment, increased availability, and lower cost of ownership. Various subscription levels are available, ranging from Platform as a Service, where the NMO manages the servers, to Infrastructure as a Service, where Esri manages the software but not the application, and Esri Managed Services, where Esri can supply, tailor, and support a custom solution in the cloud.

Community Basemaps

The Esri Community Topographic Basemap is a recent addition to the routes to market for NMO data. This is a service provided by Esri that hosts a digital map of the world at scales from 1:500 million down to 1:1,000. The map was designed to be used as a basemap by GIS professionals and as a reference map by anyone. The map includes administrative boundaries, cities, water features, physiographic features, parks, landmarks, highways, roads, railways, airports, and buildings overlaid on land-cover and shaded relief imagery for added context.

Through Esri's Community Maps Program, organizations can contribute use of their geographic data to become part of this community map. Data is integrated with data from other providers and then published through ArcGIS Online as a map service. Only the rendered map tiles are served, so valuable vector data remains private and can still be sold by its owner if desired.

Users inside and outside an organization will be able to use the online maps with ArcGIS mapping applications or a standard Internet web browser. This eliminates the costs associated with making the data widely available, such as setting up and maintaining the infrastructure.

Data Sharing

In addition to printed maps and equivalent soft-copy visual outputs, NMOs have to make available a wealth of vector, raster, and image data complete with associated metadata.

Vector

Vector data has historically been made available as CAD or GIS datasets on physical storage media containing complete feature data for multiple themes for standard areas. For the large volumes of framework data held by NMOs, this is still appropriate for some users, and ArcGIS (particularly with the Data Interoperability extension) handles any required format.

However, for many NMOs there is a move toward distributing vector data as an online "pull" process, where clients can request data for particular themes and areas of interest. They also can ask for incremental updates—just the changes since an earlier date. With

its standards-compliant Web Feature Service (WFS) capabilities, ArcGIS for Server is central to this approach.

Raster

Raster data output is needed for the datasets that continuously vary across the terrain, such as DEMs, slope or aspect data, or population density. ArcGIS provides raster export capabilities from ArcGIS for Desktop plus Web Coverage Service (WCS) from ArcGIS for Server.

Imagery

Aerial photography and remotely sensed imagery can be output or served using the same capabilities as those used for raster data. In addition, it can be dynamically processed and served through the ArcGIS Image Extension for Server (see esri.com/software/arcgis/arcgisserver/image-extension.html) as high-performance image services for web or intranet distribution.

Metadata

Metadata is "data about data." Data users need access to metadata to help them locate appropriate datasets and understand their content. Publishing metadata facilitates data sharing. ArcGIS supports simple searches in ArcGIS Online as well as comprehensive metadata creation, storage, editing, and query facilities. These support metadata standards, including the ISO 19115 standard and INSPIRE Implementing Rules.

Portals

Esri Geoportal Server (formerly the GIS Portal Toolkit) allows an NMO to catalog the locations and descriptions of organizations' geospatial resources in a central repository, called a *geoportal*, and publish them to the Internet or the NMO's intranet. Visitors to the geoportal can search for and access these resources to locate and maximize their use of the NMO's products. Geoportal Server is supplied by Esri as open source software, encouraging community development.

Online Services

Online services are at the heart of a modern NMO's distribution framework. ArcGIS for Server is the Esri component that makes maps, features, rasters, processes, and tasks available as web services.

Map Services

Image map services, such as those using the Open Geospatial Consortium, Inc. (OGC), Web Map Service (WMS) protocols, provide the fundamental geographic framework to many websites. ArcGIS for Server provides a range of such services, including cached map services for instant pan and zoom and very fast dynamic map services.

Feature Services

Feature services, such as those using the OGC WFS and Transactional Web Feature Service (WFS-T) protocols, provide the ability to retrieve the coordinates and attributes for particular features and hence build solutions that query and interact with NMO data entities (parcels, buildings, roads, etc.). Feature services are also at the heart of new lightweight data capture and update strategies using applications on mobile devices (handhelds, smartphones, tablets, etc.).

Coverage Services

Raster data services, such as those using the OGC WCS protocol, provide the ability to retrieve raster data such as elevation models and use it in web clients.

Mashup Services

All the above services use standard-conforming interfaces, so that their outputs can be combined as mashups, bringing together disparate sources to discover the synergy between them. To aid in this, ArcGIS for Server also supports de facto standards such as the KML and KMZ formats.

Geoprocessing Task Services

In addition to retrieval services, ArcGIS for Server exposes the full functionality of the geoprocessing framework and its associated ModelBuilder models as task services, allowing web clients to be built that can process NMO data, including updates and modification as well as analyses.

Search, Query, and Geocoding Services

The final set of services is composed of ones that return answers to questions. ArcGIS for Server will geocode addresses or place-names to provide locations or return feature sets based on attribute or spatial queries.

User Interfaces and APIs

Web user interfaces and application programming interfaces have been evolving at blinding speed over the past few years. New technologies such as REST, Silverlight, Flex, and JavaScript have been adopted by ArcGIS. They have replaced the static web mapping of the past with dynamic, responsive, appealing, highly functional visual interfaces, as is increasingly expected in this web 2.0 world. Esri has released for free use a set of APIs and template applications for JavaScript, Silverlight, and Flex as well as ones for .NET and Java—see the ArcGIS Resource Center at resources.esri.com/arcgisserver/index.cfm?fa=applications.

NSDIs

Geoportals provide a major technology component of a spatial data infrastructure. An SDI is a framework of technologies, policies, and institutional arrangements that together facilitate the creation, maintenance, exchange, and use of geospatial data and related information resources across an information-sharing community. National SDIs are at the heart of many nations' e-government strategies and contribute upward to pan-national data sharing initiatives such as the European INSPIRE Directive. Esri has solution tools, such as ArcGIS for INSPIRE, to facilitate SDI standards compliance—see esri.com/software/arcgis/arcgis-for-inspire/.

E-commerce

National framework data is a valuable asset, and many NMOs have business models that require that access to map and data products be controlled and priced. ArcGIS for Server and Portal for ArcGIS have the infrastructure to facilitate the construction of e-commerce sites, and Esri works with partners such as con terra GmbH and ILS to provide flexible solutions for e-commerce.

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Conclusion The previous sections have presented the ArcGIS platform and shown how it fulfills the requirements of NMOs. The components of ArcGIS work together in a unified system across an NMO enterprise for collecting, managing, and producing products and then sharing them.

The ArcGIS System
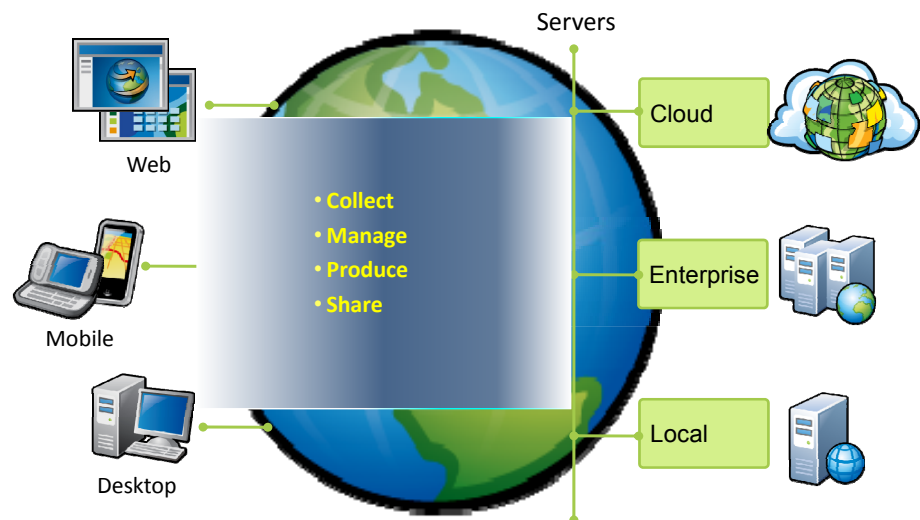
The ArcGIS system provides a complete infrastructure to an NMO for making maps and land and geographic information available throughout the organization, across a community, for a nation, or openly on the web. It can be implemented on individual local desktops, on enterprise servers, or across browsers and mobile applications that draw on the power of central servers. Such ArcGIS servers can be provided within the NMO for maximum control or be hosted in the cloud for lower overhead and maximum scalability.

In these days of financial pressures, increased requirements, and reduced resources, NMOs can benefit greatly from adopting an enterprise GIS.

Appendix 1—GIS Workflow and Quality for NMOs

Workflow Tools
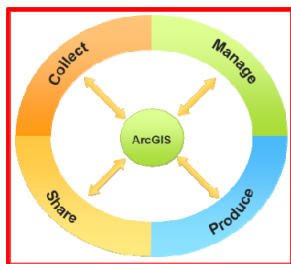
NMOs require workflows and tools to create an efficient and cost-effective production line, linking the tasks of collecting, managing, producing. and sharing. Workflows facilitate tasks such as compiling, editing, quality control, and job tracking. With the Esri Production Mapping extension, ArcGIS has the right tools for map and data production organizations to minimize button clicks and ease and control the flow of operator tasks, increasing efficiency and meeting the demand of production schedules.

Workflow Management

The primary component for workflow is the ArcGIS Workflow Manager extension, formerly known as Job Tracking for ArcGIS (JTX™). This simplifies and automates many aspects of job management and tracking and streamlines the workflow, resulting in improved efficiency and significant time savings. The workflow management functionality guides users through the necessary GIS and non-GIS tasks required to complete the entire business process.

With Workflow Manager, users can improve their productivity by automating common activities such as geoprocessing and version management, thereby reducing repetition of production procedures; ensure standardization and consistency across operations; easily track workflow status using reports; efficiently manage a dispersed work force; and assign activities by geography.

Workflow Manager provides tools for allocating resources and tracking the status and progress of jobs. A detailed history of work activity is automatically recorded to give managers and supervisors a play-by-play report of how the job was completed. This information can be supplemented with comments, notes, supporting documents, and notifications to capture even richer job documentation and communication in a single centralized repository. For more information, see esri.com/library/whitepapers/pdfs/ jtx-workflow-mgmt.pdf.

Quality Control/ Quality Assurance

The ArcGIS system contains many embedded tools and facilities for establishing and maintaining data quality. The main quality coordinating component is ArcGIS Data Reviewer, an extension that provides a set of QA/QC tools to simplify many aspects of spatial data quality control. NMOs have a vital need to review, correct, and validate data quality throughout a project.

Data Reviewer simplifies the QC process for such organizations by providing a variety of automated checks that can immediately improve data integrity. These include spatial, attribute, topology, connectivity, database validation, and z-value checks. It can identify geometric corrections, missing or extraneous features, and where feature attribution

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changes must be made. Many such defects can be automatically fixed, and for ones where human intelligence is needed, it guides the operator through visiting, correcting, and checking all the possible error situations. For more information, see esri.com/software/arcgis/extensions/arcgis-data-reviewer/.

Appendix 2—Standards, Data Models, and Templates

Standards and Interoperability

Esri is committed to building open and interoperable commercial off-the-shelf software products. Esri has always been and continues to be a keen advocate of open access to geographic data and software functionality, using widely adopted, practical standards. Esri's current products have appropriate open application programming interfaces and support key data interchange formats and web services standards for ensuring relevant GIS and IT interoperability.

ISO

The Esri products and geodatabase architecture comply with open concepts and standards for interoperability, particularly the International Standards Organization 191xx series of geographic information standards. For more details, see the Esri white paper on standards at esri.com/library/whitepapers/pdfs/supported-ogc-iso-standards.pdf.

OGC

Another important family of standards for geospatial and location-based services is from the Open Geospatial Consortium, Inc. Esri has long been a principal member of the OGC and actively contributes to the OGC standards process. OGC conformance is described in the white paper mentioned above.

KML

In addition to the de jure standards from official bodies, some de facto standards are established by frequent use; Esri also supports these—notably the KML and KMZ formats.

INSPIRE

European Parliament and the Council of the European Union (EU) in March 2007 published a directive establishing an Infrastructure for Spatial Information in the European Community. This is aimed at making spatial data concerning a range of themes from hydrography and roads to addresses and parcels available in a consistent form across all the countries of Europe. Esri has contributed to the evolution of the INSPIRE standards, such as the Implementing Rules for each theme.

To let NMOs meet their INSPIRE responsibilities, Esri has built a coherent set of tools and data models for INSPIRE conformance. ArcGIS for INSPIRE includes INSPIRE service tools, combining Esri Geoportal Server with tools to match the INSPIRE schemas. It simplifies and expedites the setting up of the requisite INSPIRE-compliant discovery, view, and download services. For more information, see esri.com/inspire/.

Data Models and Templates

GIS data model examples and templates can help NMOs jump-start their database and product definition process. Esri provides a number of relevant data models as possible starting points and has documented a methodology for data modeling. It also has cartographic style templates in the form of sample map documents and layer definition files.

Data Model Methodology

The Esri Press book *Designing Geodatabases: Case Studies in GIS Data Modeling* (esripress.esri.com/display/index.cfm?fuseaction=display&websiteID=85) is a highly visual guide to creating a dynamic geographic data model. It helps ArcGIS users design

schemas that have comprehensive and descriptive query definitions, user-friendly cartographic displays, and increased performance standards. It outlines five steps for taking a data model through its conceptual, logical, and physical phases—modeling the user's view, defining objects and relationships, selecting geographic representations, matching geodatabase elements, and organizing the geodatabase structure. Several design models for a variety of applications are considered, including addresses and locations, census units and boundaries, stream and river networks, and topography and the basemap.

Industry Solutions

Esri's industry-specific solutions are prepopulated with a collection of data models, map series templates, and specific map surround elements to ensure that digital data meets quality standards and is then effectively represented in the final map or chart products.

Esri Production Mapping

The Production Mapping solution (formerly PLTS™ for ArcGIS—Mapping Agency Solution) is designed to efficiently produce and maintain topographic database and map products that meet European and US specifications and can be extended to meet other nations' specifications. It was developed specifically for high-volume database production, maintenance, quality control, and high-quality cartographic output.

Esri Defense Mapping

This includes production tools to efficiently create and maintain military specification-compliant data and map products. It includes data loading, editing, and quality control production tools and numerous defense-specific geodatabase models.

Esri Aeronautical Solution

This addresses the complexity of managing aeronautical information in a central GIS database. It facilitates production and maintenance of aeronautical charts and transfer of aeronautical information via the Aeronautical Information Exchange Model (AIXM). The solution allows users to produce International Civil Aviation Organization (ICAO) and national specification chart products (including instrument approach and departure, en-route, and visual charts) via one-touch, database-driven cartography from a central aeronautical database.

Esri Nautical Solution

This is used to produce a seamless nautical database from a variety of sources and perform maintenance on existing datasets. The solution enables high-volume production and maintenance of Electronic Navigational Charts (ENCs) according to the S-57 standards of the International Hydrographic Organization (IHO).

Sample Esri Data Models

Esri has organized the creation of many industry-specific data models to simplify the process of implementing projects and systems and promote and support standards. Academic and industry leaders have collaborated with Esri to create and design data model templates, which have then evolved via industry feedback.

A list of available model templates is available on the Esri Support download page at support.esri.com/index.cfm?fa=downloads.dataModels.matrix. Among the more relevant to NMOs are Address, Agriculture, Basemap, Forestry, Geology, GIS for the Nation, Homeland Security, Hydro, Land Parcels, Local Government, National Cadastre, and Transportation.

Standard Domain Models

Along with the Esri-initiated sample models described above, there are models available arising from de jure and de facto standards.

| EuroGeographics | EuroGeographics established European standards for EuroRegionalMap and EuroGlobalMap. Data models for these are now included in template resources of the Esri Production Mapping solution. |

- The EuroRegionalMap project has created a pan-European (over 30 countries) vector topographic database at scale 1:250,000 (medium scale). It is used as reference data and an enabling spatial analysis and geographic backdrop for presentation and visualization based on the harmonization of already existing national databases of the NMOs.

- EuroGlobalMap is a similar topographic dataset that covers the whole of Europe at the scale 1:1 million.

| INSPIRE | The data models for the 35 INSPIRE themes are being defined by the INSPIRE Implementing Rules committees, set up by the European Union. Geodatabase data models for the Annex 1 themes are included in the ArcGIS for INSPIRE solution (see esri.com/inspire/). |

| Military | There are several military models that are relevant to NMOs, but a recent one is defined as being part of the Multinational Geospatial Co-Production Program. This is a coalition originally of 27 nations but now growing to 32 nations and participating in production of global, high-resolution vector geospatial data at scales of 1:50,000 or 1:100,000. Data models for all MGCP specifications are included in the Esri Defense Mapping solution. |

| *ArcGIS.com Resources* | The ArcGIS.com website has a wealth of resources contributed by Esri and other users, including data models and templates. |

| Community Basemap | The templates used by Esri and its customers in creating the Community Topographic basemap (described in the Share section above) are provided as downloadable resources. These include preprepared high-quality cartography as well as data model schemas and sample data for a range of scales of topographic mapping. |

Appendix 3—Finding More Information

Web Resources

- The Esri home page at esri.com is the starting point for a wealth of information on products, services, and so forth.

- For details on map, chart, and data production, visit esri.com/maps, which includes user success stories.

- For details of available training courses, both instructed and self-paced, see the training pages at training.esri.com.

- For cartographers, the Esri Mapping Center at mappingcenter.esri.com provides best-practice information, hints, and tips to help you make great maps with ArcGIS.

- The ArcGIS.com home page at arcgis.com will lead you to galleries of information and online services, including basemaps, templates, and layer packages.

- The resources pages at resources.arcgis.com provide online resources for developers, users, and managers. Examples include the following:

  - The Imagery resource center at resources.arcgis.com/content/imagery/10.0/about

  - The Esri Production Mapping resources at resources.arcgis.com/content/esri-production-mapping/10.0/about

  - ArcGIS Workflow Manager resources at resources.arcgis.com/content/workflow-manager/10.0/about

  - The ArcGIS Data Reviewer resource center at resources.arcgis.com/content/data-reviewer/10.0/about

  - Geoportal Server resources at resources.arcgis.com/content/geoportal-extension/10.0/about

  - Esri Aeronautical Solution at resources.arcgis.com/content/esri-aeronautical-solution/10.0/about

  - Esri Nautical Solution at resources.arcgis.com/content/esri-nautical-solution/10.0/about

  - Esri Defense Mapping solution at resources.arcgis.com/content/esri-defense-mapping/10.0/about

  - ArcGIS for INSPIRE resource center at resources.arcgis.com/content/arcgis-inspire/1.0/about

Books   Esri Press, with its catalog at esripress.esri.com, publishes many useful books on GIS, cartography, and related subjects. Those of particular relevance to NMOs include the following:

- Building a GIS: System Architecture Design Strategies for Managers
- Building European Spatial Data Infrastructures
- Cartographic Relief Presentation
- Designed Maps
- Designing Better Maps
- Designing Geodatabases
- GIS and Land Records
- Introduction to Geometrical and Physical Geodesy
- Land Administration for Sustainable Development
- Lining Up Data in ArcGIS
- Map Use: Reading and Analysis, Sixth Edition
- Modeling Our World
- Semiology of Graphics
- The Look of Maps

Esri inspires and enables people to positively impact their future through a deeper, geographic understanding of the changing world around them.

Governments, industry leaders, academics, and nongovernmental organizations trust us to connect them with the analytic knowledge they need to make the critical decisions that shape the planet. For more than 40 years, Esri has cultivated collaborative relationships with partners who share our commitment to solving earth's most pressing challenges with geographic expertise and rational resolve. Today, we believe that geography is at the heart of a more resilient and sustainable future. Creating responsible products and solutions drives our passion for improving quality of life everywhere.

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