BUILDING A CANADIAN DIGITAL DRAINAGE AREA FRAMEWORK

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Abstract

This paper describes an inter-departmental initiative involving Natural Resources Canada, Environment Canada, Statistics Canada and Agriculture and Agri-Food Canada to develop a national framework of digital drainage areas. There are currently a variety of digital GIS databases depicting Canada's drainage area network. This joint project integrates drainage area boundary information from several sources into a single national-scale framework supporting both the Water Survey of Canada and National Atlas definitions. There has been consultation with several provincial agencies to ensure a harmonized approach and to avoid duplication of effort.

The resulting drainage area dataset has been tightly integrated with the national 1:1 000 000 scale hydrology (rivers and lakes) layer. Built-in codes support a simple SQL query for tracing and estimating the drainage area upstream of a user-defined point. In addition, over 3000 Water Survey of Canada hydrometric stations have been located in the drainage area framework. The dataset for the drainage area framework will be available publicly on the Geogratis website operated by the Canada Centre for Remote Sensing. It will be spatially compatible with other environmental frameworks (e.g. soil polygons) and socio-economic frameworks (eg. census sub-divisions) also tied to the national 1:1M base.

Résumé

Le présent document décrit un projet interministériel qui a amené Ressources naturelles Canada, Environnement Canada, Statistique Canada et Agriculture et Agroalimentaire Canada à collaborer à l'élaboration d'un cadre national de données numériques sur les bassins hydrographiques.

Il existe déjà une variété de bases de données numériques du SIG (Système d'information géographique) qui décrivent le réseau de bassins hydrographiques du Canada. Le projet conjoint dont il est question ici intègre l'information sur les limites des bassins hydrographiques, tirée de plusieurs sources, dans un cadre unique à l'échelle nationale qui tient compte des définitions de Relevés

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hydrométriques et de l'Atlas national. On a consulté plusieurs organismes provinciaux afin d'harmoniser l'approche et d'éviter le chevauchement des travaux.

L'ensemble de données sur les bassins hydrographiques qui en résulte a été étroitement intégré à la couche de données hydrologiques nationales (rivières et lacs) à l'échelle de 1/1 000 000. Des codes intégrés permettent de faire une demande en langage relationnel pour tracer et estimer le bassin hydrographique en amont d'un point configuré par l'utilisateur. En outre, plus de 3 000 stations hydrologiques de la Division des relevés hydrologiques du Canada sont répertoriées dans ce cadre.

Le public pourra accéder à l'ensemble de données du cadre des bassins hydrographiques sur le site Web de GéoGratis de l'Atlas national. Le cadre sera spatialement compatible avec d'autres cadres environnementaux (par ex., polygones terrestres) et des cadres socio-économiques (par ex., subdivisions du recensement) qui sont également liés à la base de données nationales à l'échelle de 1/1 000 000.

Introduction

A variety of digital base maps depicting Canadian drainage areas exist at present:

(a) The Water Survey of Canada (WSC) has drainage area boundaries on paper maps (1:2M scale). These boundaries were digitized by Environment Canada in the 1980's.
(b) Statistics Canada's Environmental Accounts division digitized the WSC boundaries separately and integrated them with a base derived from the Census files. The coastline in this file was generalized from various scales of data.
(c) The National Atlas created a digital file of drainage areas tied to its 1:7.5M base and used this to produce paper maps for the 5^{th} Edition of the National Atlas. The criteria used to define these drainage areas were different than those used by Environment Canada.
(d) Several other agencies (e.g. the Prairie Farm Rehabilitation Administration), provinces, and conservation and hydropower authorities have compiled regional and local digital drainage area boundaries.
(e) Large hydroelectric projects (eg. James Bay) significantly change the hydrologic base and these changes are not maintained in a uniform manner.

As a result, organizations requiring a consistent, integrated, and up-to-date set of drainage area boundaries at a regional or national scale must recompile some of these boundaries. It thus becomes time-consuming to merge their work with other projects based on a different basin framework. As freshwater issues become increasingly numerous and complex in Canada, the need for a single national framework becomes more pressing.

The objective of this inter-departmental initiative is to integrate drainage area boundary information from several sources into a single national-scale framework supporting both the Water Survey of Canada and National Atlas definitions. It is desirable that such a framework is accepted by and available to all levels of government, NGOs, academics and the value-added industry. The main collaborators at this point have been Natural Resources Canada, Environment Canada, Statistics Canada and Agriculture and Agri-Food Canada, but there has been consultation with several provincial agencies to ensure a harmonized approach and to avoid duplication of effort.

This paper describes the approach taken and the results achieved to date in building a national drainage area framework for Canada.

Two National Drainage Area Hierarchies

The Water Survey of Canada (or, as it was known then, the Department of the Interior, Dominion Water Power Branch) first developed, in 1922, a Water Resources Index Inventory as a convenient and logical system for recording and filing water resources data. It was designed for the storage of such information as the location of waterpower sites, waterpower developments, storage reservoirs, stream measurement stations, and meteorological stations. The Water Survey of Canada delineations involved the division, sub-division and sub-sub-division of Canada into suitably sized areas based on the drainage, for administrative purposes. Although the boundaries are based on drainage, the intent was to include all of Canada's land mass and waters within this drainage area hierarchy to facilitate the identification of hydrometeorological sites. Therefore, the WSC drainage areas do not necessarily define individual river basins, but can represent intervening areas along the coast or include islands.

In 1985, the National Atlas of Canada produced a 1:7.5M-scale "5th Edition - National Atlas of Canada - Drainage Basins" map which depicts the drainage basins for many of the larger rivers of Canada. The National Atlas basin hierarchy has 5 levels, the first of which defines Canada's five ocean drainage areas and covers all of Canada's land mass and waters. The second level defines major river basins and intervening areas and also covers Canada's entire land mass, while the remaining three levels define important river basins without defining the intervening areas or islands. The major criterion used to define a National Atlas basin was a mean annual discharge of at least 280 m^3/s at the mouth or confluence of the river. (The exceptions to this are the Assiniboine, Qu'Appelle, Souris, Battle, Red Deer and Oldman rivers).

Clearly, the WSC classification and the National Atlas classification had very different design goals. Nevertheless, our investigation found a high degree of similarity between the two hierarchies. After correcting for apparent errors in the original WSC design, the correlation between the National Atlas drainage areas and the WSC areas is very high. Approximately 95% of the National Atlas boundaries are also WSC boundaries – meaning that, with few exceptions, the National Atlas basins can be derived from the WSC sub-sub-division areas.

Geoconnections and Framework Data

Since 1998, the Geoconnections group of Natural Resources Canada has been involved in designing and implementing the Canadian Geospatial Data Infrastructure, or CGDI. Data infrastructure projects are seen as essential in many nations, to provide a base for the development of an information economy, similar to how transportation and power infrastructures provide a base for the industrial economy. One component of the CGDI, and thus a major thrust of Geoconnections, is framework data.

The definition, and especially the practical implementation, of Canadian framework data is still evolving. However, at the time of writing, it is expected that Canadian framework data will be developed as a collection of datasets called the Geobase. These will be a series of datasets covering essential themes, particularly the geodetic framework, the data alignment layer, imagery, roads, land and marine elevations, land and marine hydrology, and administrative boundaries [Geoconnections, 2001]. There will be two levels of detail supported: the Geobase level 0 will have a nominal scale of 1:1M and will be intended for projects working on a national or large regional scale. The Geobase level 1 will be much more detailed, although probably of varying resolution in different areas of the country.

This project to create a national drainage area framework has received funding from the Geoconnections Frameworks node. It has been designed from the beginning to build on and be entirely consistent with a new national database for rivers and lakes, known as Geobase Level 0 hydrology, which was released in January of 2001.

Methodology

Design Goals

Inspired by the successful development of the Geobase level 0 hydrology database, representatives of the Meteorological Service of Canada (Environment Canada), the GeoAccess Division (Natural Resources Canada) and the

Environmental Accounts and Statistics Division (Statistics Canada) met in early 2000 to design a project for the delineation of drainage areas of Canada, specifically, to create a Geobase level 0 drainage area database. Each agency involved had specific requirements for the result, and certain design goals to be met.

Firstly, there was one set of drainage areas defined by Environment Canada and another by the Geo-Access Division. Statistics Canada had compiled statistics using the Environment Canada boundaries, and many Canadian users had used at least one of the two sets. Therefore, it was agreed that a major goal for the project would be to support both definitions, making the minimum number of changes and corrections to bring the data into line with known problems.

A second goal was that the drainage area framework be compatible with and connected to the Geobase level 0 hydrologic (rivers and lakes) framework. The latter had been designed from the beginning to place analytical soundness ahead of cartographic appearance. This analytical focus was proving successful in practice as more agencies used the structure for its original application (automated generalization), and new applications of the analytical structure were being found. Therefore, both the drainage area boundaries and point features of the new framework would be explicitly and topologically integrated with the hydrologic network. Furthermore, it was important to make the topological properties accessible through standard query mechanisms, as not all users are willing to support the advanced and often custom software needed to compute these properties.

When the project began, there was no low-cost digital elevation model (DEM) of adequate resolution covering all of Canada available. Nor were there initially available any digital drainage area boundaries at satisfactory resolution. Therefore, the original project design was to use the network of rivers and lakes in the Geobase level 0 hydrologic framework to locate the drainage boundaries. Since that time, both DEM data and more detailed drainage boundary reference data have been acquired. A preliminary investigation of the Geobase Level 0 Digital Elevation Model indicated that the 1-kilometre pixel spacing was too coarse for analyzing drainage patterns in many areas. However, reference data derived at scales of 1:250,000 or better have been used to supplement the hydrologic network and guide the positioning of the drainage area boundaries. The use of these two relatively independent sources has provided extensive quality control of the underlying hydrologic network.

Data Model

The Geobase level 0 drainage area database consists of two types of datasets. The primary datasets are those that are built, maintained and edited as part of this project, while the secondary datasets are derived from the primary datasets when required using automated methods.

The Geobase level 0 hydrology data, upon which the drainage area framework is based, is formed of three primary datasets – the skeletons, the lakes and the islands. The skeleton dataset consists of a linear representation of the river systems and coastline. A virtual linear feature, or skeleton, passes through water bodies to allow network analysis routines to compute flow through lakes. The lakes dataset consists of water area features (which may include double lined rivers), while the islands dataset represents holes in the area features. A virtual skeleton feature is always contained within a water area feature, but it might intersect islands. A secondary "combo" dataset is produced from these three primary datasets for cartographic purposes. This has had the virtual network features removed, and islands reinserted into the lake features, so that it can be used to provide a pleasing visual representation for mapping.

The skeleton dataset includes, within its attributes, pre-computed coding schemes to allow for both automated generalization and rapid upstream tracing. Both of these schemes are designed to allow any system capable of SQL queries to perform either of these tasks. This reduces the need for users of these datasets to support complex network analysis systems themselves.

The new drainage area framework features three new primary datasets: the *drainage area* dataset, the *drainage point* dataset, and the *boundaries within lakes* dataset. The *drainage point* dataset contains hydrometric gauging stations, hydropower generating stations, and potentially other point features. Each is explicitly linked to a node in the skeleton dataset using a unique identifier. (It is possible for more than one gauge or hydropower station to be linked to the same node.) In most cases, the point feature is co-located with the node, but in the case of hydrometric gauging stations on lakes, the actual point feature may be quite far from its effective position in the hydrologic network.

The *drainage area* dataset consists of a set of polygons associated with the features in the skeleton dataset. Every feature in the skeleton network drains a defined area on the ground. The boundaries of these areas often represent the boundaries between drainage areas in the WSC or National Atlas hierarchies. The locations of these boundaries are derived from more accurate reference datasets when available.

Finally, the *drainage area* dataset is supplemented by the *boundaries within lakes* dataset, which delineates those WSC boundaries which subdivide major lakes.

Several secondary datasets may be produced from the *drainage area* dataset. By a process of "dissolving" boundaries in the *drainage area* dataset, any level in the WSC or National Atlas hierarchy of drainage areas may be produced. Also, the area that drains through any skeleton feature may be identified by a process of “tracing” the area upstream of that point feature. This process is used to produce a *point drainage area* dataset consisting of drainage areas associated with each point (e.g. hydrometric stations) in the *drainage point* dataset.

These different datasets are illustrated in Figure 1:

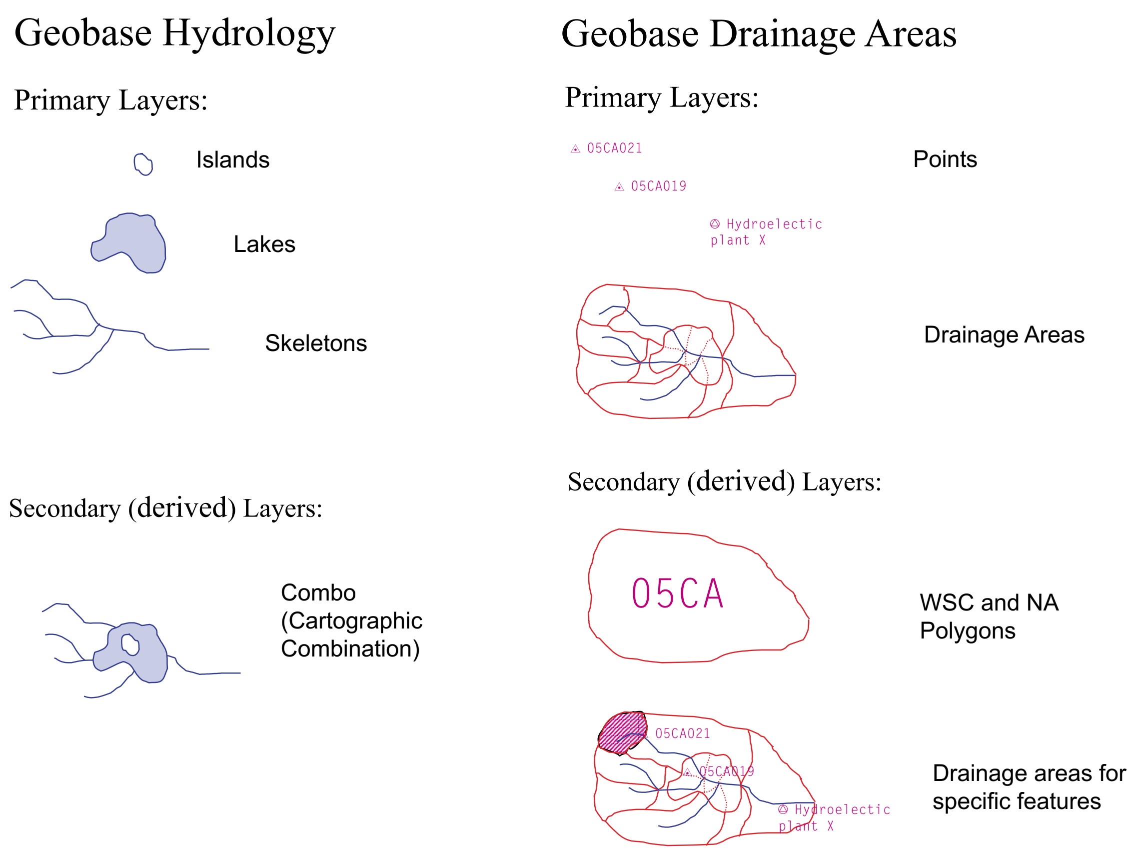


Figure 1: Primary and Secondary Datasets in the Geobase Hydrology and Drainage Area Frameworks

Fundamental Drainage Area Units

One of the design goals was to support both existing area hierarchies in a single dataset. Since, in most cases, the National Atlas drainage areas or basins are composed of one or more complete WSC sub-sub-divisions, the latter is generally considered to be the fundamental drainage area unit. Generally, any desired level in either hierarchy can be generated using the rollup tables and the WSC sub-sub-divisions.

However, there were certain cases – primarily around river mouths - where this property did not hold. For these few cases, it was necessary to further subdivide the WSC sub-sub-divisions. Figure 2 illustrates such a case in the area of the

Rivière Betsiamites. Here, the National Atlas drainage unit is the entire basin for the Rivière Betsiamites, defined as starting from the mouth of the river. This basin is made up of the WSC sub-sub-divisions 02SA and only part of 02SB. Therefore, in this area, 02SB was subdivided into 02SBA and 02SBB.

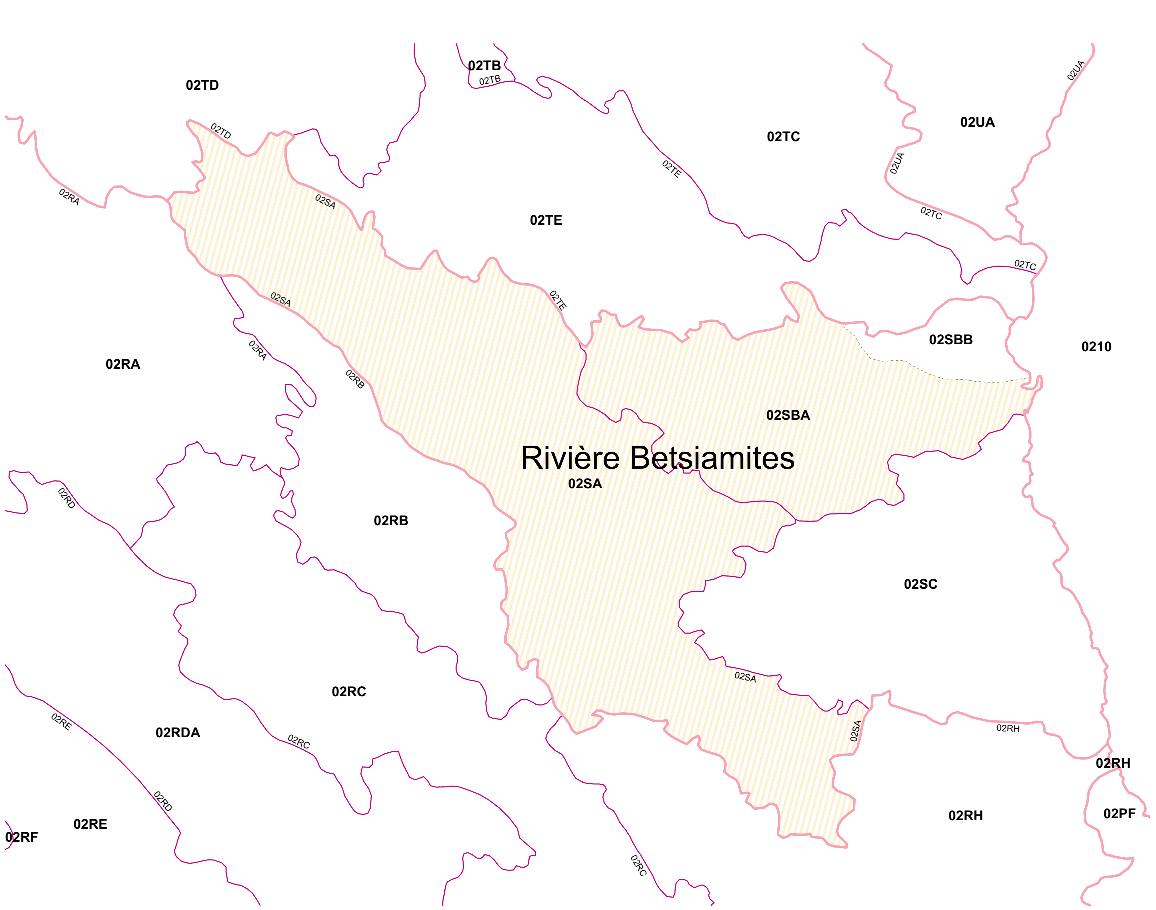


Figure 2: Differences between WSC and National Atlas Drainage Hierarchies in the Area of Rivière Betsiamites

Source material

The primary source material for the project were the Geobase level 0 hydrologic framework (rivers and lakes); the Water Survey of Canada 1:2M drainage area boundaries (Statistics Canada digital version); and the National Atlas 1:7.5M drainage basins database .

In addition to these sources, the following reference material for drainage boundaries was obtained for the different regions of Canada.

Table 1 : Reference Datasets for Drainage Area Boundaries

Province/Territory	Source Agency	Source Scale
Newfoundland and Labrador	No additional data	
Nova Scotia	Nova Scotia Geomatics Centre (NSGC)	1:50 000
Prince Edward Island	PEI Department of Fisheries, Aquaculture & Environment	1:10 000
New Brunswick	No additional data	
Quebec	No additional data	
Ontario	Environment Canada, Ontario Region with data contributed by Ontario Ministry of Natural Resources, Ontario Hydro and Ontario Ministry of Environment	1:250 000
Manitoba	Prairie Farm Rehabilitation Administration (PFRA, Agriculture and Agri-Food Canada)	1:50 000
Saskatchewan	Prairie Farm Rehabilitation Administration (PFRA, Agriculture and Agri-Food Canada)	1:50 000
Alberta	Prairie Farm Rehabilitation Administration (PFRA, Agriculture and Agri-Food Canada)	1:50 000
British Columbia	British Columbia Ministry of Environment - Fisheries Branch, as modified by Environment Canada, Pacific and Yukon Region	1:50 000
Yukon Territory	Environment Canada, Pacific and Yukon Region	1:1 000 000
North West Territories	Environment Canada, Western and Northern Region, and Wallace Engineering	1:250 000
Nunavut	Environment Canada, Western and Northern Region, and Wallace Engineering	1:250 000

The hydrologic point features were obtained from three sources: metadata for WSC gauging stations were obtained from Environment Canada's HYDEX database. Nearly 4000 active or discontinued hydrometric stations with drainage areas of at least 200 km^2 were considered for this project.

Hydroelectric generating station data were obtained from Statistics Canada's hydropower generating station database and Natural Resources Canada's small hydropower generating station database. In the majority of cases, Statistics Canada's dataset included those hydroelectric generating stations in the small hydropower database. Therefore, Statistics Canada's dataset was treated as the primary source of information for this type of feature.

Procedure

The project consisted of two main efforts, each being somewhat independent of the other. Firstly, it was necessary to review the design of, and then develop accurate boundaries for the drainage areas and basins belonging to both the WSC and National Atlas hierarchies. This was approached by first designing a set of fundamental drainage area units compatible with both hierarchies and then integrating that with the set of areas produced for each arc in the Geobase hydrology dataset. Secondly, the point features from the source databases had to be associated with nodes present in the Geobase hydrology skeleton dataset in order for their drainage areas to be computed.

Creation of 1:1M Drainage Area Boundaries for WSC & National Atlas Definitions

The goals of this component of the project were straightforward, to produce a set of drainage areas which:

- would be spatially compatible with the Geobase hydrology
- would incorporate accurate boundary data where it was available,
- would use reasonable estimation techniques where references were not available,
- would support analytical queries, such as upstream tracing
- would be possible to maintain with a reasonable amount of effort.

This was undertaken in a seven stage process. The requirement for a maintainable dataset meant that automatic techniques had to be used, and the absence of a DEM meant that these techniques had to derive their information from the stream network. A technical overview of how that was approached follows the description of the process.

a) Revisions to the Statistics Canada version of the WSC Database

The very first task was to thoroughly review the definitions of the drainage areas in both hierarchies. Based on this review, some changes were made to the definition of the WSC boundaries, and verified by EC regional personnel. In cases where the WSC and National Atlas boundaries did not agree, further breakdowns of the WSC sub-sub-divisions were created.

b) Data Refinement

The primary source data for this project was the Geobase level 0 hydrology (rivers and lakes) database. The source datasets were the separated Skeleton, Lake and Island datasets, rearranged to correspond to the major drainage basins of the WSC definition. Some of the major basins were split further along sub-basin lines, resulting in 13-15 working datasets covering all of Canada.

c) Roll-up Determination

The national framework of drainage areas supports two hierarchies, the WSC and the National Atlas. Using the smallest units defined in stage a, each hierarchy was defined in terms of roll-up tables and a topological sorting of these divisions. Furthermore, a correspondence was established between the National Atlas and WSC boundaries such that the National Atlas boundaries can be "rolled up" from the WSC sub-sub-division level.

d) Identification of Drainage Basin Origins

In the process to automatically define a drainage area, the origin of each drainage area must first be identified. The origin is defined as the most downstream arcs within an area. Once known, the data structure permits a rapid tracing of these arcs to upstream arcs to define the contributing drainage area.

At the lowest level of definition, most of the WSC and National Atlas areas are "incremental drainage areas", not the total drainage area above a point. These incremental areas are later rolled up to define the higher-level drainage basins and areas. The incremental drainage area is computed as the drainage area immediately upstream of the origin, and does not include upstream incremental drainage areas.

e) Automated Creation of Drainage Areas

Using the downstream arcs, the drainage areas for the WSC and National Atlas were computed using an automated procedure that delineates the perimeters of connected stream networks, as defined by the Geobase Level 0 hydrology database.

f) Adjustment of Drainage Area Boundaries for WSC and National Atlas definitions

The computed areas were then manually inspected and adjusted based on all available reference drainage area information. Every area was inspected, although certain areas had to rely on the Statistics Canada's dataset of WSC boundaries. This process of inspection and adjustment effectively compared two completely independent derivations of these drainage area boundaries. This independent comparison provided an excellent quality control on the hydrologic network.

g) Creation of final “constrained” voronoi

Once the boundaries of each of each drainage area or basin were adjusted, it was necessary to regenerate the individual areas for each feature in the Geobase hydrology. These generated areas were constrained to fit within those boundaries adjusted in step f. This way, the individual areas required to support upstream tracing and other queries could be generated automatically, while maintaining the accurate information developed in the previous stage.

Creation of 1:1M Drainage Area Boundaries for Hydrometric Gauging Stations and Hydropower Generating Stations

The second component of the project was to associate the point features from the source databases with nodes in the skeleton dataset. Once associated with a node, it was then possible to compute the area draining through a particular point feature, using the coding scheme present in the skeleton attributes, and the areas defined in the first stage of this project. There were two phases to this part of the project. Part a proceeded in parallel with the drainage area development, while part b was clearly dependent on the drainage areas being complete.

a) Identification of hydrometric gauging station and generating station points

Hydrometric gauging and generating station points were associated with a node in the hydrologic network. (If an appropriate node did not exist on a river, it would be created) All inflowing rivers to those nodes are considered to contribute flow at the gauge or generating station. Three separate point databases were attached to the hydrologic network, namely:

1. Hydrometric gauging stations
2. Existing hydropower generating stations
3. Small hydropower generating stations

If the river or lake corresponding to the station was not found in the hydrologic network, the point could not be attached to the network, and so the station was excluded. Each point was integrated into the network as a node whose topological position in the network corresponds to its effective position in the river system. That is, if the gauging station (or hydropower generating station or small hydro station) represented by the point is downstream of a particular river on the ground, it was attached downstream of that river in the hydrologic network. For most gauges this is extremely close to the gauge's actual position. However, for lake level gauges, the effective position in the network is considered to be the mouth of the lake. This can be quite far from the actual position of the gauge, and therefore lake level gauges may not be co-located with their associated node.

b) Creation of drainage areas corresponding to river and lake gauging stations, plus attribution

Once the station nodes were created, drainage areas were computed for all stations, using an automated procedure and the final drainage area boundary dataset. Polygon names and numbers were added as attributes.

Derivation of Drainage Area Boundaries using Network Analysis and Voronoi Diagrams

Today, the most common way to derive drainage area boundaries and analyze hydrologic flow is to use a digital elevation model, and compute watershed and stream lines on it. However, in the absence of a DEM, and with the requirement to integrate varying levels of reference data into the final product, it was necessary to develop an alternate methodology. The methodology used here for deriving basins from the stream network uses the Voronoi diagram of the stream network. This method has been used in a few other projects previously, notably the British Columbia TRIM Watershed Atlas [Barrodale, 2002]. The Voronoi software used in this project was developed by the National Atlas using a combination of custom software, Shewchuk's "Triangle" [Shewchuk, 1996] and ESRI's ArcInfo.

Given a set S (possibly infinite) of points in a plane, the Voronoi diagram V of S is the set of all points with at least two nearest neigbors in S. Algorithms for computing the Voronoi diagram of a finite set of points are commonplace. However, a set of line segments, such as a river network, consists of an infinite set of points. Computing the Voronoi diagram of a set of line segments is a computationally challenging problem and algorithms for doing so [e.g. Held, 2001] are complex. For the application at hand, the Voronoi diagram may be approximated using a densified set of vertices of the river system [Gold, 2001].

The Voronoi diagram may be used to associate an area on the ground with each feature in the network. Analysis of the network can then be used to define regions on the ground by collecting together those areas. Specifically, in step d of the seven-stage process discussed earlier, the most downstream arcs in a basin were identified – effectively this fixes the definition of the unit relative to the hydrologic network. All arcs in the unit can be found by tracing upstream from the most downstream arc (stopping at the point upstream where a new basin is defined.) Following that, in step e, areas on the ground can be determined by enumerating the areas associated with these arcs.

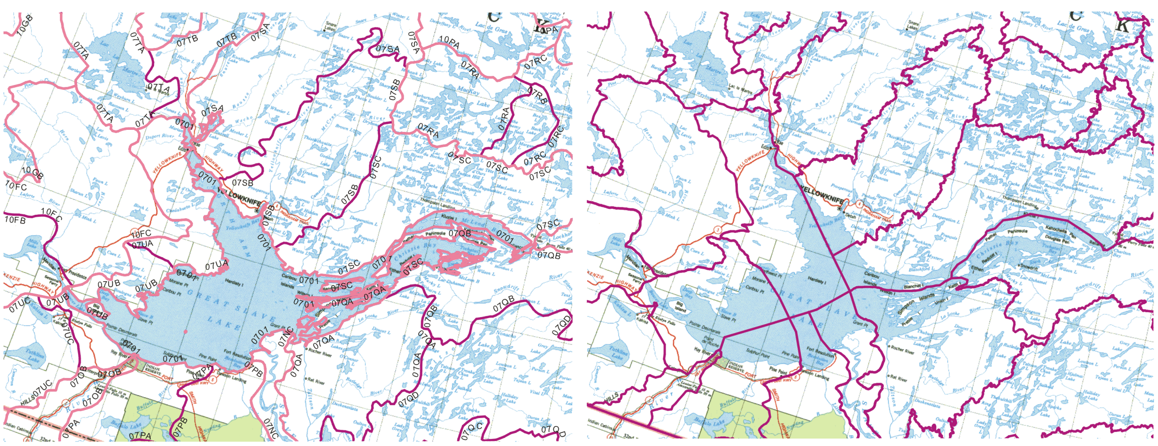
This process is also used in step b of the procedure to delineate drainage areas associated with each drainage point. Tracing upstream from a hydrometric gauging station or hydropower generating station will delineate all those arcs and in turn all those areas which drain through that point. Based on the coding in the attributes of the skeleton dataset, this process can be performed for any arbitrary arc, using a fairly simple SQL query.

The Voronoi approach also allowed a very rigorous quality control process to be put in place to check the traditional WSC and National Atlas boundary definitions. Clearly, if the latter boundaries crossed the stream network in hydrologically illogical ways, then it would be difficult or impossible to match them with the generated boundaries. Conversely, if the stream network was incorrectly constructed, there would be difficulty in generating the boundaries.

In practice, this methodology proved to be both a burden and a blessing. By forcing this correspondence between the stream network and the drainage area boundaries, the quality of both the Geobase level 0 hydrologic framework and the new drainage area framework has been greatly improved. Unfortunately, difficulties related to these quality issues did introduce delays in completing the project. Assuming that the hydrologic network accurately reflects the situation on the ground, all rivers that drain through a particular point on the network may be enumerated by tracing upstream all possible branches from that point. Since an area on the ground is associated with each feature in the stream network, then it is possible to also trace out the area on the ground that drains through that particular point in the network.

Limitations introduced by lakes

Lakes introduce some complexity into the modelling process. In most cases, it is difficult to state exactly what is meant by being upstream of half a lake. Nevertheless, WSC boundaries are in some cases defined to partition large lakes. The network model would not easily support this model, so large lakes were defined as their own basin, and the basins draining into them defined as stopping at the shore. For reference purposes, there is a cartographic supplement to the area coverage that defines the WSC area boundaries inside those lakes. This situation is illustrated in Figure 3.



When defined for the network analysis software, the boundaries of drainage areas may not subdivide lakes. For analysis purposes, large lakes such as Great Slave Lake have been assigned their own sub sub division.

As shown here, however, the actual Water Survey definitions subdivide the lake. These subdivisions internal to the lake are provided in a separate cartographic coverage.

Figure 3: Changes to sub-sub-divisions near major lakes to allow network analysis

Constraining the Voronoi Diagram to Agree with Known Data

In those areas of the country where more accurate reference data was available, it was desirable to incorporate it into the area coverage. However, there were many areas which were not covered by reference data, and the reference data did not include the level of detail present in the results of the Voronoi process. In order to take advantage of the more accurate reference data where it was available, but to maintain the versatile querying ability of the highly detailed area coverage, it was necessary to construct the area coverage using the Voronoi algorithm, constrained to use the reference data boundaries where available.

To achieve this, each fundamental drainage area unit is considered to have a fixed boundary. Within that boundary a set of drainage areas is generated for each stream arc by the method described, and constrained to remain within the boundary. The collections of small areas, each contained within one of the smallest drainage units, are then collected together to form the final area dataset. The result is illustrated in Figure 4.

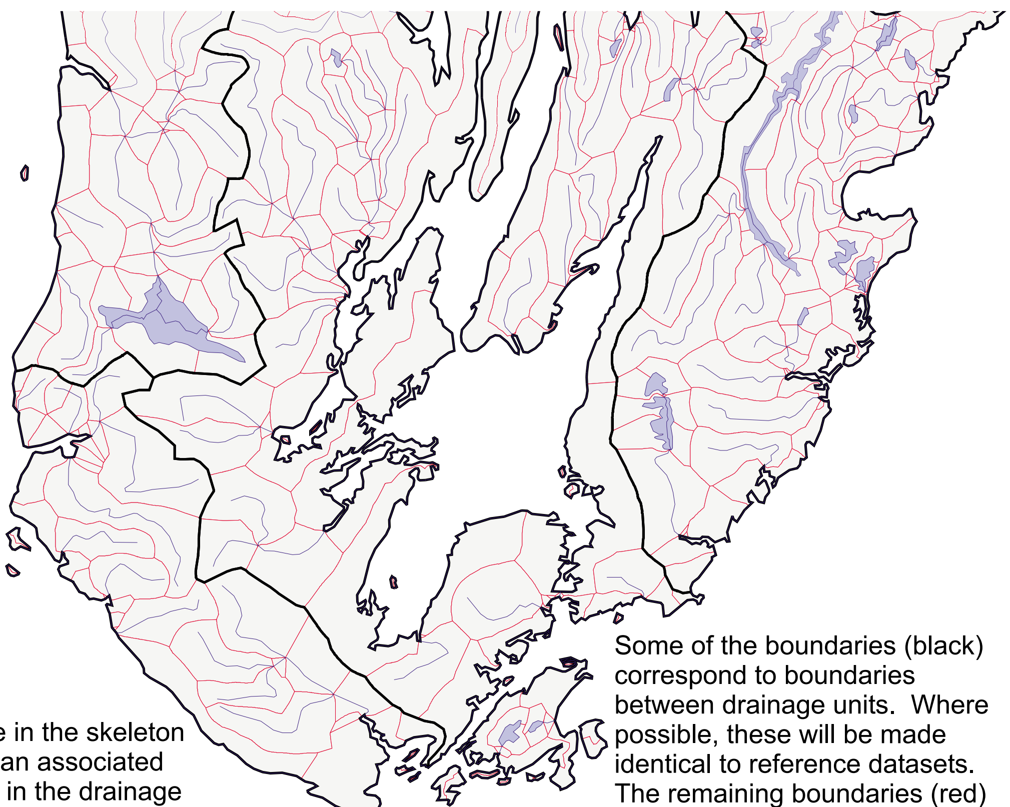


Figure 4: Constrained and unconstrained boundaries in the drainage areas.

Results

Changes to Existing Basin Definitions

As a result of the extensive review made of the national drainage area hierarchies, about 13% of the original WSC sub-sub-divisions were affected in some way, while only 3-4% of the boundary lines were changed. While this does pose some difficulty, as some WSC hydrometric stations will have to be re-numbered, we believe that the benefits associated with a more accurate and consistent dataset overwhelmingly outweigh the difficulties. Figure 5 highlights those areas that have been changed

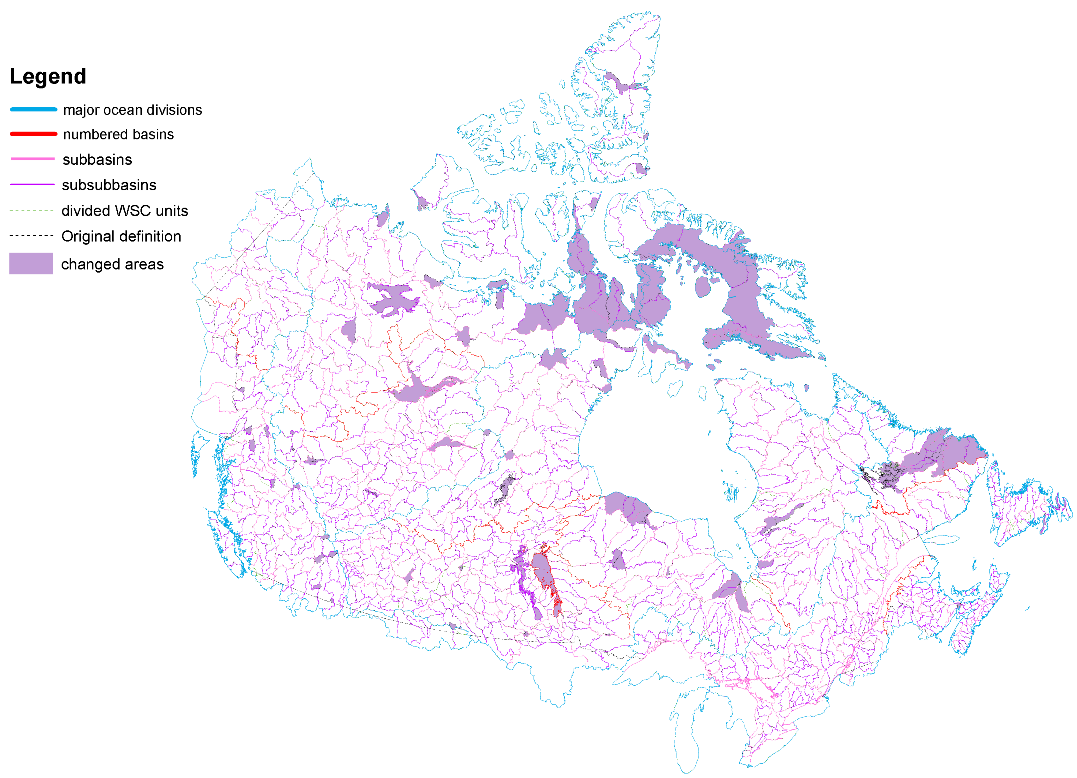


Figure 5: Areas where the definition of the Water Survey sub-sub-divisions have changed

In addition to these changes, 44 WSC sub-sub-divisions (out of 963 in total) were further subdivided into 2 or 3 smaller units, primarily to support the National Atlas hierarchy.

Hydrologic Network Quality

Our methodology forced us to have the hydrologic (rivers and lakes) network correct in order to get reasonable results on locating drainage area boundaries. Although we attempted to minimize the number of changes to the hydrologic network, for time reasons, many changes were made to reflect correct connectivity and flow. While most of these were relatively minor, the number is still significant.

The editing of the Geobase hydrology to provide improvements as a result of the Drainage Areas Framework is ongoing at the time of writing. The scope of the improvements can be estimated by the number of changes reported by the version control system in place at the National Atlas. To date there have been a total of 8366 changes (5181 changes to skeletons, 2834 to lakes and 351 to islands) to the hydrology datasets. This represents changes to 1.2% of the features maintained in the databse. We expect that number to approximately double by the time the project is complete, resulting in a noticeable improvement in data quality.

Results of Locating Drainage Area Boundaries

Like the hydrologic network edits, the editing of the drainage area boundaries is ongoing at the time of writing. Results to date however, show that over the entire dataset there are approximately 274 000 km of relevant drainage boundary between WSC sub-sub-divisions. (Coastlines, lake shores and the boundaries between the largest units must be fit to the Geobase level 0, and are not considered in this estimate.) Of these, approximately 58%, or 158 000 km exactly match the more accurate reference datasets. A further 33%, or 91 000 km match the Statistics Canada 1:2m dataset. (The Statistics Canada dataset was the only reference available over large areas of the country.) Over those areas completely covered by the more accurate reference data, 142 000 or 71% of a total 198 000 km of boundary are identical to the reference datasets. We anticipate that that percentage will rise somewhat as editing proceeds.

Results of Locating Points

When a point was fitted to the drainage network, there were a number of reasons why it might not be fitted correctly. The two most obvious reasons were that the river in question did not appear in the drainage network , and another reason is that the description of the point in question was inadequate for fitting it into the network.

At the time of writing, the work on the hydroelectric generating station points was still proceeding so results cannot be reported. The processing of the WSC hydrometric stations has been completed with the result that of the 3842 points proposed for inclusion in the dataset, fully 3482 of them, or 90.6% have been successfully integrated with the hydrologic network.

Access and use of the data

At the time of writing, the national drainage area framework database has not been completed. When released in late 2002, it will be made freely available, in keeping with the Geobase philosophy. In the meantime, preliminary versions of the data are being made available online at http://geogratis.cgdi.gc.ca/download/temp/drainage_area/. In addition, the custom software used in the generation and analysis of the stream network and voronoi diagram is being freely released as a separate project.

The coding schemes used for the upstream tracing and generalisation applications are embedded as attributes in the final product. As a result, no sophisticated network analysis tools will be required in order to do queries such as upstream tracing. An ArcView extension has been created to automate the query process for that system. A similar query application may be developed using any system that supports the SQL standard.

Conclusions

The national drainage area framework dataset has been tightly integrated with the national 1:1M-scale hydrology (rivers and lakes) layer. Built-in codes support a simple SQL query for tracing and estimating the drainage area upstream of a user-defined point. In addition, over 3400 Water Survey of Canada hydrometric stations have been located in the drainage area framework. The datasets for the drainage area framework will be available publicly on the Geogratis website operated by the Canada Centre for Remote Sensing.

There are many benefits to having a national framework of drainage areas:

1. It is a very useful dataset for regional and national applications
2. It is spatially compatible with other digital environmental frameworks (e.g. soil polygons) and socio-economic frameworks (e.g. census sub-divisions) which are also tied to the Vmap 1:1M base.
3. It is compatible with international datasets prepared in conjunction with the Global Mapping Program
4. It links a fundamental drainage area framework to a publicly-available and internationally-used base map
5. It is publicly-available through GeoGratis

6. There is an awareness of related digital drainage area databases, developed at different scales and for different purposes, that can be used in conjunction with the national framework.
7. Adoption of this framework by government departments ensures more reliable and consistent maintenance of the data and facilitates interchange of environmental data between agencies
8. The value-added geomatics industry can now save time and energy when creating applications and products relating to drainage area boundaries.

Suggestions for further work

From both the source agencies' and users' points of view, it is also desirable to have information about and links to related digital drainage area databases, developed at different scales and for different purposes, that can be used in conjunction with the national framework. This framework has been designed to permit feature/name linkages to more detailed drainage area frameworks at larger scales.

In the course of undertaking this project, it has become clear that there is additional work that should be done to achieve and maintain a national drainage area/basin framework. Contacts have been made with many provincial agencies and several reference datasets have been identified and are being used to validate our work. However, the focus to this point has been on re-creating the national (1:1M) cover. We are now well-positioned to develop a more "interactive" network with the provinces and other interested agencies and take the framework to the next logical level. This could, for example, include a Geogratis-based website linking and providing access to all related provincial and federal databases.

As we contacted the provinces, we found that some (e.g. Ontario, Quebec and New Brunswick) have major projects underway to develop large-scale watershed boundaries. The data were not ready and so we could not use these datasets in this project. However, they could be used in the future to update the national cover we are now developing. Clearly, the current project should not be regarded as a one-time effort, but one that we should evolve in collaboration with the provinces..

In general, we feel that the next steps for the National Drainage area Framework include the following areas of effort:

1. a national federal-provincial workshop to formalize (as appropriate) a federal-provincial network of data suppliers and to address issues of data access/linking/exchange (e.g. standards). Data users would also be asked to participate.

2. the development and maintenance of a Drainage Area Framework webpage on Geogratis

3. the updating/refinement to the national drainage area database using additional provincial datasets, based in part on feedback from data users

4. the appropriate addition of data related to glaciers

References

Barrodale Computing Services. 2002. TWA Watershed Delineation. http://www.barrodale.com/single_pages/tour.htm Last Accessed May 17, 2002

Geoconnections, 2001. Framework Data Strategy. http://www.geoconnections.org/english/rfp/announcements/moreinfo/RFP_SD_strategy.pdf. Last Accessed May 17, 2002.

Gold, C. Crusts, Skeletons and Terrain Modelling. Presentation at Dagstuhl Seminar 01191. May 2001.

Held, M. 2001. VRONI: An Engineering Approach to the Reliable and Efficient Computation of Voronoi Diagrams of Points and Line Segments. Computational Geometry: Theory and Application 18(2): 95-123, 2001.

Shewchuk, J. R. 1996. Triangle: Engineering a 2D Quality Mesh Generator and Delaunay Triangulator. First Workshop on Applied Computational Geometry (Philadelphia, Pennsylvania), pages 124-133, ACM, May 1996. Also available online http://www-2.cs.cmu.edu/~quake/tripaper/triangle0.html Last Accessed May 17, 2002.