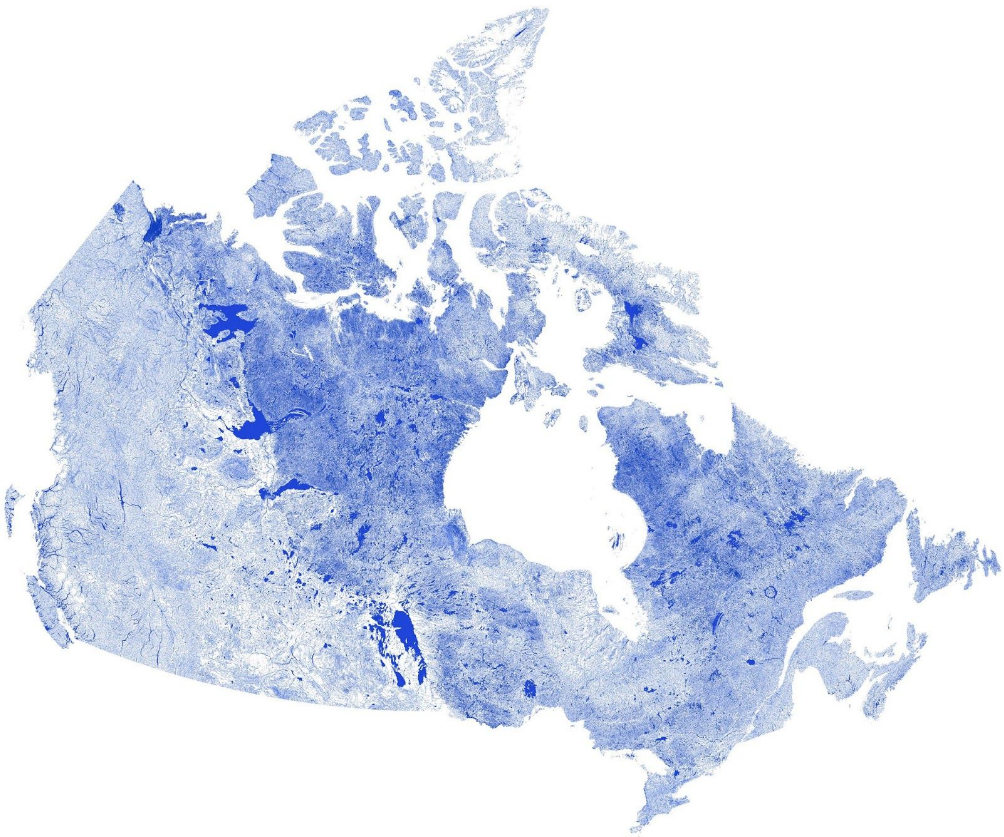
CHyF Model Constructs, v0.20



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Date: 2017 December 8

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1 Context

The Common Hydrology Features model, or CHyF, defines hydrographic and related hydrologic features of interest to hydrologists, water managers, ecologists, and others with a clear interest in water resources. Within Canada it will be a separate product suite from the National Hydro Network (NHN). However, the NHN will serve as one of the primary inputs across Canada in the creation of CHyF.

The CHyF model will be guided in large measure by HY_Features (HyF), an emerging conceptual model sponsored and approved by the Open Geospatial Consortium and the World Meteorological Organization. It is also directly influenced by the results of the Jan-Feb 2017, cross-Canada online hydro harmonization survey. The United States Geological Survey (USGS) manages their National Hydrography Dataset (NHDPlus V2 and NHDPlus HR) models and datasets. This work is also taken directly into account.

A principal test area in the Champlain-Richelieu watershed will be used, but other test areas with very different terrain will be required as well. The tests will be aimed at generating CHyF features accurately and consistently through automated processing. The tests though will deal principally with small areas to minimize data management tasks at this early stage.

CHyF will include not just data. Also envisioned are a series of web services. These services are out of scope of the current document. They will be addressed at a later stage and will be influenced by the findings of the survey noted above.

The CHyF effort has benefited from interaction with Canadian experts, but also a number of key individuals in the USGS who have contributed to HY_Features or the NHD developments, as will be described in the Acknowledgments section of a further version of this document.

2 Objectives

This document provides model constructs that define key elements of a general domain model for CHyF. The specific objectives are as follows:

- To determine what features should be included in CHyF
- To determine how those features relate to the HyF model and existing NHN features
- To develop a preliminary CHyF domain model with classes and relationships

Further assessment and testing will lead to iterations of the domain model presented here. The generation of CHyF features is out of scope of the current document but will be an integral part of the testing that is to occur.

The HY_Features document 14-111r5.docx, made available in June 2017, describes a conceptual model. All references to HY_Features in this document refer to 14-111r5.docx. The model concepts in CHyF are taken directly from HY_Features where practical. In some cases features contained in the NHN are of interest that are not described in HY_Features. In other cases, new concepts are introduced where deemed highly relevant or clearly backed by the hydro harmonization survey. These details are presented in the material that follows.

3 Principal Constructs

CHyF considers hydrographic features and derived hydrologic features to be hydro features. Hydrographic features such as lakes and rivers are those that are typically demarcated on a map; thus they include visible water features as well as associated names. From these features and a hydrologically conditioned DEM it is practical in most cases to generate derivative hydrologic products such as flowpaths and catchments that are also considered as core components of CHyF.

For pedagogic reasons, observed features collected by various mapping methodologies are distinguished from inferred features that can be algorithmically generated and typically not mapped through direct observation.Within the CHyF paradigm this distinction is not of particular importance, but users should be aware of it nonetheless.

In figures 1 and 2, the colour of the boxes helps provide context. Similar classes are shown in the same tone. A black boundary means that the class corresponds exactly, or in a few cases approximately, to a class in HY_Features. A red boundary means that it represents a net new class not available in the HY_Features model.

3.1 Observed Hydrographic Features

Hydrographic features may be considered as falling into three groups: hydrography, channels, and hydro feature names, as shown on Figure 1 below.

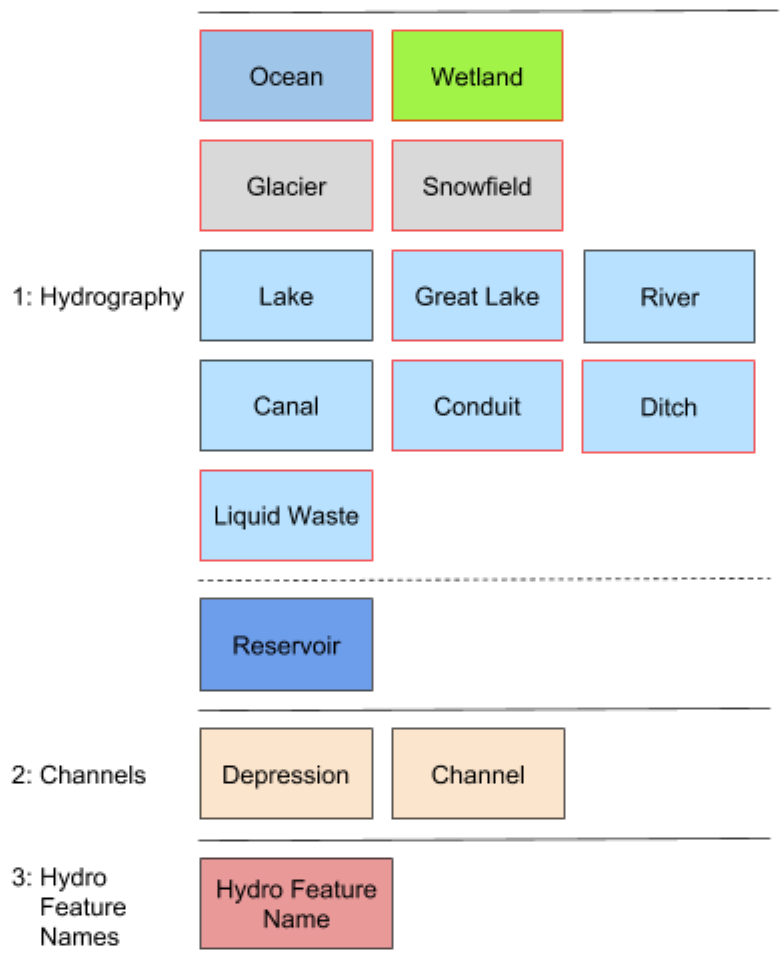

Figure 1: CHyF hydrographic features

Table 1 below provides definitions of each of these classes and shows how they relate to Hy_Features classes and National Hydro Network types.

CHyF	HyF	NHN	Notes
Ocean	--	Littoral (shoreline of ocean is provided)	Incompletely defined; CanVec data may also be an input
DEFINITION: A large body of saline water constituting a principal part of the hydrosphere. In addition to the major oceans, marine bays, straits, and other subdivisions of the ocean may be considered as ocean features. SOURCE: extended from [Princeton]() and [Wikipedia]()			
Wetland	--	--	From National Wetland Inventory or other source. Types could be specified, such as bog, fen, swamp.
DEFINITION: A transitional, regularly waterlogged area of poorly drained soils, often between an			

aquatic and a terrestrial ecosystem, fed from rain, surface water or groundwater. Wetlands are characterised by a prevalence of vegetation adapted for life in saturated soil conditions. SOURCE: WMO			
IceSnow	--	--	Abstract superclass; not in Figure 1; includes Glacier, Névé, Snowfield subclasses
DEFINITION: Perennial cover of either ice or snow. SOURCE: after Anderson			
Glacier	--	--	From Geographical Names and CanVec?
DEFINITION: A mass of snow and ice continuously moving from higher to lower ground or, if afloat, continuously spreading. The principal forms of glacier are: inland ice sheets, ice shelves, ice streams, ice caps, ice piedmonts, cirque glaciers and various types of mountain (valley) glaciers. A glacier flows downhill under gravity (through internal deformation and/or sliding at the base) and is constrained by internal stress and friction at the base and sides. SOURCE: WMO			
Snowfield	--	--	From Geographical Names
DEFINITION: Accumulations of snow and firn that did not entirely melt during previous summers. Snowfields can be quite extensive and thus representative of a regional climate, or can be quite isolated and localized, when they are known by various terms, such as snowbanks. Another term for firn is névé. SOURCE: after Anderson			
Waterbody	Equivalent	Waterbodies + Single Line Watercourses	Abstract superclass; not in Figure 1; includes Lake, River, Canal, Conduit, Ditch and LiquidWaste
DEFINITION: Mass of water distinct from other masses of water. SOURCE: HY_Features			
Lake	Equivalent	Waterbody, of type Lake and Pond	
DEFINITION: A body of surface water, participating in a hydrographic network; it is special due to its considerable size and the lack of significant observable flow except at inflows and outflows. A lake may or may not be regulated. SOURCE: after HY_Features and Anderson			
GreatLake	--	Bank (shoreline of lake is provided)	Incompletely defined; CanVec data may also be an input. It could be considered as a type of lake, but because its behaviour is so different and because models for the Great Lakes are often different from those for more typical lakes.
DEFINITION: One of the Laurentian Great Lakes of North America or other very large lakes that have much in common with oceans or inland seas. They are conceptualized as different from a typical lake, with potentially different associated methods and attributes.			
River	Equivalent	Watercourse	In HyF, the term stream is

			also used, but it does not appear in the UML. A stream may include “an open or closed conduit, a jet of water issuing from an orifice, or a body of flowing groundwater”.
DEFINITION: A body of surface water, participating in a hydrographic network; it is special due to its property of permanent or temporary flow. SOURCE: HY_Features			
Canal	Equivalent	Canal	
DEFINITION: A body of surface water, participating in a hydrographic network, special due to its artificial origin (man-made) and its permanent or temporary flow. SOURCE: after HY_Features			
Conduit	--	Conduit	Assuming that in HyF a river and stream are the same, then the note above applies.
DEFINITION: An artificial system, such as an aqueduct, penstock, flume, or sluice, designed to carry water for purposes other than drainage. It may also be used to describe urban infrastructure drainage channels. SOURCE: extended from NHN Data Catalogue (GeoBase_NHNC1_Data_Catalogue_EN.pdf)			
Ditch	--	Ditch	
DEFINITION: A small, open manmade channel constructed through earth or rock for the purpose of conveying water. SOURCE: after NHN Data Catalogue (GeoBase_NHNC1_Data_Catalogue_EN.pdf)			
Liquid Waste	--	Liquid Waste	
DEFINITION: Liquid waste impoundment associated with an industrial complex. SOURCE: NHN Data Catalogue (GeoBase_NHNC1_Data_Catalogue_EN.pdf)			
Reservoir	Equivalent	Reservoir	Must be restructured
DEFINITION: A body of water, either natural or man-made, used for storage, regulation and control of water resources. By recognizing Reservoir as a separate class, descriptions and services pertaining to storage characteristics can be managed separately from those of waterbodies. SOURCE: after HY_Features			
Depression	Approximate	--	May be based just on DEM. Hydrographic features may or may not follow exactly the surface depressions and indentations extracted from the DEM. Rules will need to be defined regarding the boundaries of a depression.

DEFINITION: A land feature that is lower than the surrounding land and acts as a container for surface water. Water may or may not be present at any given time. SOURCE: HY_Features			
Channel	Approximate	--	As noted for Depression
DEFINITION: A specialization of Depression that may be a natural or man-made, open or closed, course through which water may or may not flow. SOURCE: HY_Features			
Hydro Feature Name	Equivalent	Toponymy	
DEFINITION: An object supporting the assignment of a referenceable name for all or parts of a hydrologic feature; it provides a pattern to handle cultural, political and historical variability of names. SOURCE: HY_Features			

Table 1: CHyF hydrographic features and their correspondence to HyF and NHN features

A DEM (raw or not hydrologically conditioned) is not included in Table 1 because it is not considered a hydro feature in its own right.

3.2 Derived Hydrologic Features

Figure 2 below shows classes for network, catchment and nexus features that are derived from instances of the hydrographic feature classes above and a DEM. Hydro locations are also shown.

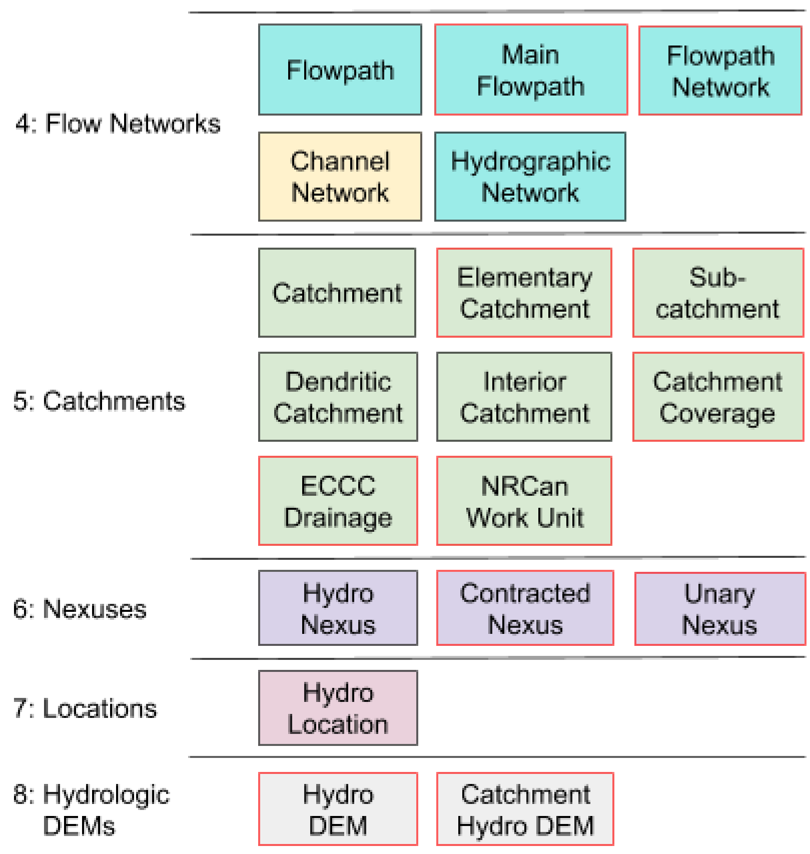

Figure 2: CHyF derived features

For the derived features above, Table 2 below provides definitions and the corresponding Hy_Features and NHN feature types.

CHyF	HyF	NHN	Notes
Flowpath	Approximate	Network linear flow	
DEFINITION: A derived linear feature that realizes a catchment specifically as a path connecting the inflow or headwater start point with the outflow of the catchment. A flowpath may be designated as either primary or secondary, with primary flowpaths forming a dendritic structure. A flowpath may be instantiated as a single, directed linear segment or a series of connected, directed linear segments. For an elementary catchment, the flowpath is defined as a single linear segment. For a larger more encompassing catchment, the flowpath may be defined as a series of end-to-end connected linear segments equivalent to a single geometric curve. (The variance from HyF results from HyF's support for linear referencing, which is not supported in CHyF. With the approach taken by CHyF, creating an indexed graph intended for quick traversal is practical to implement; no identifiers need be visible to the user.) SOURCE: modified from HY_Features			
Main Flowpath	Informally discussed; not in UML	--	The more common term is mainstem. Can be generated from NHDPlus data
DEFINITION: A derived linear feature defined as a series of connected flowpaths, upstream from a			

hydro nexus or other location on a flowpath to a unary nexus at a headwater source; it realizes a catchment based on stream name, longest length, largest area, or estimated flow volume. Another name for main flowpath is mainstem.			
Flowpath Network	Implied	The NHN does not include an explicit equivalent to flowpath network. However, it does distinguish primary and secondary flowpaths, with the primary flows defined such that they form a dendritic pattern.	Strahler order and Horton order can be generated and stored, based on primary flows.
DEFINITION: A derived feature type that specializes the CA_HydroNetwork realization, specifically as an aggregate of connected flowpaths corresponding to the elementary catchments contained in a larger catchment.			
Hydrographic Network	Equivalent	--	
DEFINITION: A derived feature type that specializes the CA_HydroNetwork, specifically as an aggregate of permanent or temporary bodies standing in depressions or moving in channels. SOURCE: HY_Features			
Channel Network	Equivalent	--	
DEFINITION: A derived feature type that specializes the CA_HydroNetwork realization, specifically as an aggregate of surface depressions and surface channels that continuously or periodically contain water, without imposing a particular drainage pattern. SOURCE: HY_Features			
Catchment	Equivalent	--	Catchment divides could be generated if needed (as a set of linear features) from catchment areas, which are a realization of catchments. In an operational context, catchment and catchment area may be considered as equivalent.
DEFINITION: A derived feature type that specializes CA_HydroFeature to describe the area draining into a hydro nexus, which acts as the outflow for the area in question; it encompasses a flowpath network that shares the same hydro nexus outflow. It may contain other catchments and it may be contained in other catchments. Similarly it may flow into a lower catchment (or more than one lower catchment where braids or distributaries exist) and have one or more higher catchments flow into it. SOURCE: HY_Features			
Elementary Catchment	--	--	Equivalent to reach catchments in NHDPlus
DEFINITION: A catchment draining into a given hydro nexus at the lower end and bounded by the inflowing catchment(s) defined by the next upstream hydro nexus. In the case of a headwater stream,			

the elementary catchment is the area draining into the first hydro nexus moving downstream. An elementary catchment does not contain other elementary catchments, but it does contain one or more subcatchments. Every hydro nexus has at least one elementary catchment flowing into it, and two (or more) elementary catchments flowing into it if the hydro nexus is located at the confluence of two (or more) flowpaths. Elementary catchments form a geospatial coverage, with no gaps and no overlaps. An elementary catchment is equivalent to a reach catchment in the US NHDPlus.			
Sub-catchment	Used in places to describe (i) elementary catchments and (ii) subcatchment faces to the left or right of stream segments	--	Has been considered by USGS, but not part of NHDPlus
DEFINITION: A subdivision of an elementary catchment, where the elementary catchment is broken down into areas that are predominantly land or water, thus allowing for a greater degree of physiographic and ecologic homogeneity within each of the resulting sub-catchments. Subcatchments do not overlap and are space filling, forming a small coverage of the elementary catchment. An elementary catchment that is not subdivided by a land/water division can be said to contain a single subcatchment. Thus, subcatchments also form a coverage equivalent to that formed by the elementary catchments.			
Dendritic Catchment	Equivalent	--	
DEFINITION: A subclass of CA_Catchment that is characterized by a single common downstream catchment for every hydro nexus in the catchment. If both primary and secondary flowpaths exist, the network formed by the primary flowpaths corresponds to the dendritic catchment. SOURCE: after HY_Features			
Interior Catchment	Equivalent	--	
DEFINITION: A feature type that specializes the general HY_Catchment class as a catchment that is generally not connected to other catchments. SOURCE: HY_Features			
Catchment Aggregate	Equivalent	--	
DEFINITION: A specialization of the CA_Catchment type as a set of non-overlapping dendritic and interior catchments arranged in an encompassing catchment. It is not a general term for an aggregation of adjacent catchments. Instead it is intended to describe hierarchical systems that may also contain internally drained areas. SOURCE: HY_Features			
ECCC Drainage	--	As related to the ECCC drainage hierarchy	The ECCC Drainage may need to be recalculated to

			match CHyF divides in due course.
DEFINITION: A specialization of CA_CatchmentAggregate used to describe the Water Survey of Canada Drainage Area hierarchy.			
NRCan Work Units	--	NHN work units, which are not part of the NHN formal model	The NRCan Work Units may need to be recalculated to match CHyF in due course.
DEFINITION: A specialization of CA_CatchmentAggregate used to describe the Natural Resources Canada hydrographic work unit hierarchy.			
Hydro Nexus	Equivalent	Hydro junction	
DEFINITION: A feature type that conceptualizes a hydrologically determined nexus of a corresponding catchment and associated flowpath network. The hydro nexus represents the place where a catchment interacts with another catchment, i.e. where the outflow of a contributing catchment becomes the inflow into a receiving catchment. A catchment may receive flow from several upstream catchments or contribute flow to several downstream catchments through a single hydro nexus. Through shared identity, each hydro nexus feature may be associated with different realizations within a hydrologic complex given that each realization has the same hydrologic function or characteristics. SOURCE: HY_Features			
Contracted Nexus	Discussed, but not in model	--	Potentially useful as a means of relating to nexuses in HUCs
DEFINITION: A nexus that may be referenced and is intended to exist in subsequent versions of the data.The term contracted implies a social contract to maintain the given nexus. A contracted nexus is equivalent to the “contracted node” used in the Australian Hydrological Geospatial Fabric (AHGF). It is not deemed necessary to have a contracted catchment, which is recognized in the AHGF.			
Unary Nexus	--	--	Inclusion allows for construction of a directed graph from nexuses of the full schematic of a flowline network. This is not true if just hydro nexuses are available.
DEFINITION: A feature type used to specify the start of a headwater (first order) stream. A flowpath exists downstream of the unary nexus, but none is defined upstream of it.			
Hydro Location	Equivalent	--	
DEFINITION: A feature type providing the position of a hydrologically significant feature that is located on a (surface) hydro network. Examples include hydro nexus, weir, and hydrometric station. SOURCE: after HY_Features			

Hydro DEM	--	--	In scope for NHDPlus; specific rules/constraints need to be defined; technically not a hydro feature but included here for completeness since it forms the basis from which various hydro features are potentially derived
DEFINITION: A hydrologically conditioned digital elevation model. It is characterized by: (i), noise filtering and in particular pit removal of a gridded DEM, (ii), adjustment of the DEM values to ensure that they correspond to low points along observed hydro network elements, and (iii), alignment of the catchment divides with the inferred ridgelines in the DEM. Such refinements help ensure that the resulting hydro DEM is well behaved in the context of hydrologic models. Within Canada, CDEM and HiResDEM datasets would be considered as input data, along with the feature types described above, in the hydro DEM generation process.			
Catchment Hydro DEM	--	--	Most likely to be generated as needed; see above for further commentary
DEFINITION: A subset of a hydro DEM that corresponds to the terrain area covered by a catchment.			

Table 2: CHyF derived features and their correspondence to HyF and NHN features

4 Model Relationships

The relationships among the various constructs described above can be shown using the Unified Modeling Language (UML) as supported by Enterprise Architect. These constructs are defined as types or classes that collectively with their relationships define a domain model. An alphabetical listing of these classes is shown in Figure 3. With the exception of the two already existing DEM classes appearing at the bottom of the list, all classes begin with CA_ in recognition of their applicability to common applications.

Where equivalent terms are found in HY_Features, mapping between them should be direct. Where terms are found in the CHyF domain model but not in HY_Features, constructing them should be practical if the basic data elements are available. For example, the concept of an elementary catchment is a logical extension of that for catchment and could easily be specified in HY_Features using a subclass. Other features such as ocean and glacier are intentionally out of scope in HY_Features. In the UML diagrams that follow, feature types that have no HY_Features equivalent are displayed with a red boundary. Classes that are abstract superclasses, implying no direct instantiation, are italicized.

The approach taken here with CHyF has been to create a full model with no formal dependence on HY_Features. However, because as noted above many of the classes are intentionally equivalent to what is available in HY_Features, at some future point CHyF could be redefined based explicitly on HY_Features. For example, CA_HydroFeature could be a specialization of HY_HydroFeature with constraints related to implementation details. In some cases care would need to be taken because the definitions may be subtly different, as with CA_Flowpath vs. HY_FlowPath. An alternative to subclassing is conformal mapping, as might be carried out through FME scripts for example. It is too early at this point to decide on which alternative is preferred.

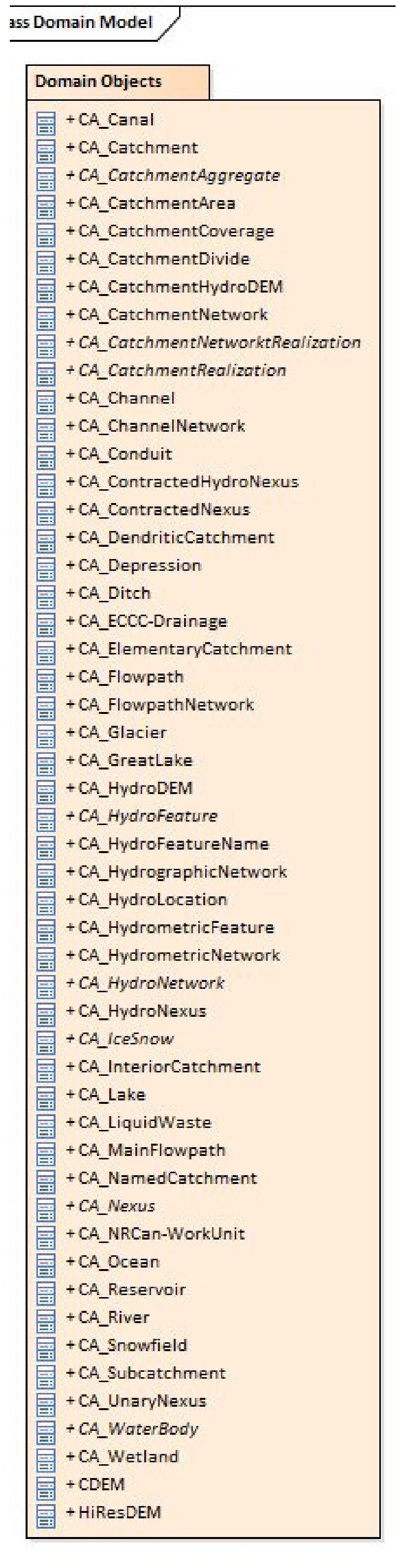

Figure 3: CHyF Domain Model Classes

Figure 4 on the right shows CA_HydroFeature as an abstract superclass, serving as the principal parent class in the model. With a couple of exceptions, only the generalize-specialize relationship is shown. Further details are shown in subsequent figures.

Catchment classes are the largest group. It contains a range of catchment concepts from elementary catchment and subcatchment to catchment coverage and both the ECCC drainage hierarchy and the NRCan work unit hierarchy. At some point these two hierarchies should coalesce, but this is not considered as realistic in the short term. Similarly, the Statistics Canada [Standard Drainage Area Classification] hierarchy, which is not shown here, should be integrated with the other two. Canada should have one national catchment aggregate that serves a variety of purposes.

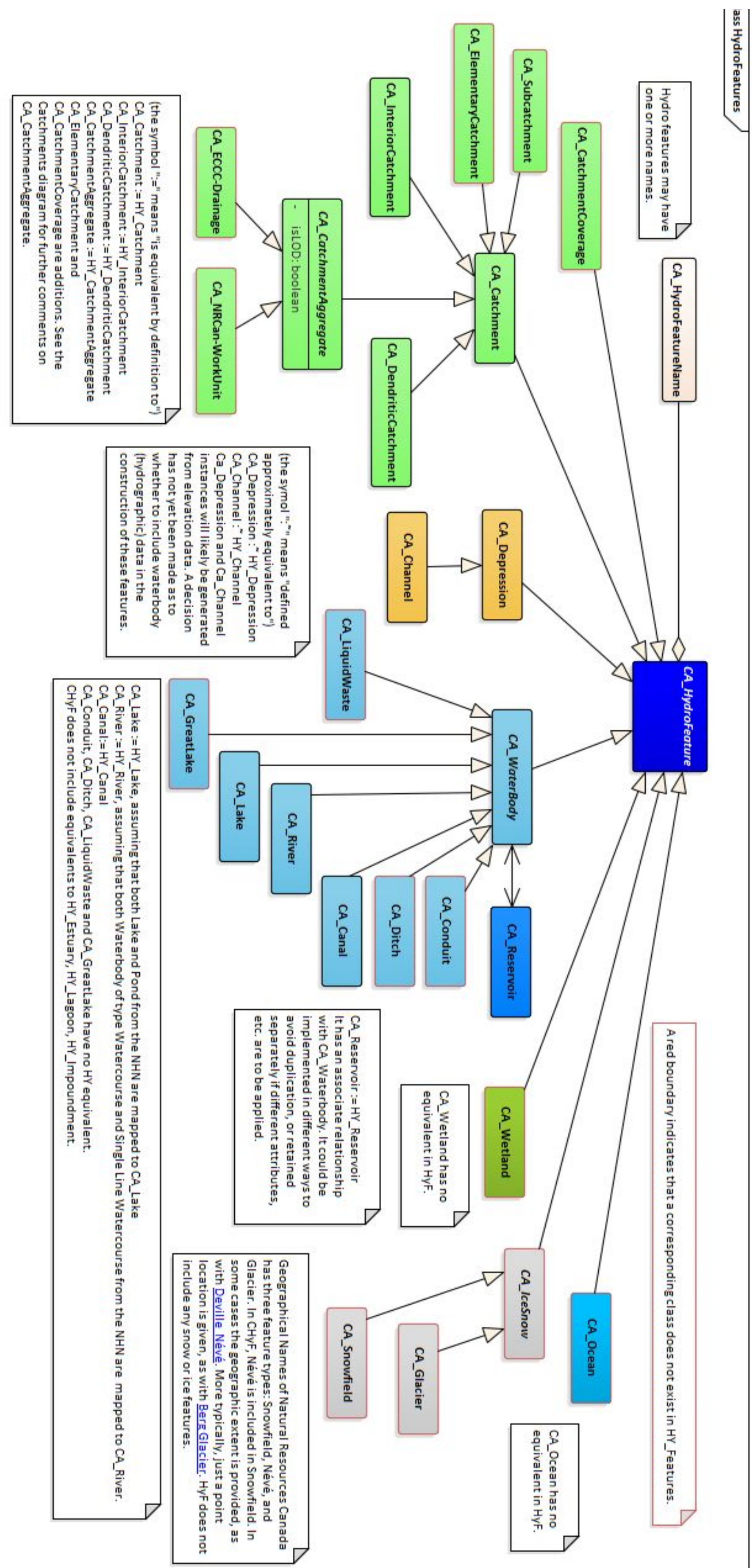

Figure 4: Hydro feature class hierarchy

Waterbodies are the next most prolific class in this diagram. Note that reservoir has a relationship to waterbody, and thus to any of its subclasses, but is not modeled as a hydro feature in its own right. So for example a lake or a section of a river may have reservoir characteristics, which would be available through this linkage. Depression and channel make up another group under hydro feature. If these are to be implemented in CHyF, decisions will need to be made establishing how they will be defined. One option is just to convey depressions as determined through a DEM; another option is to include input from both the DEM and the mapped hydrography, as is the presumed intention in HY_Features. Wetland, perennial ice/snow, ocean and great lake are other subclasses of hydro feature. Great lake is not treated as a subclass of lake because of significant conceptual differences as noted in section 3.

4.1 Catchment Classes

Figure 5 below shows more detail about catchment class relationships. As is true elsewhere, the relationships defined in HY_Features have been used here as well. However, more detail is provided in CHyF related to elementary catchments, subcatchments, and the ECCC and NRCan catchment hierarchies.

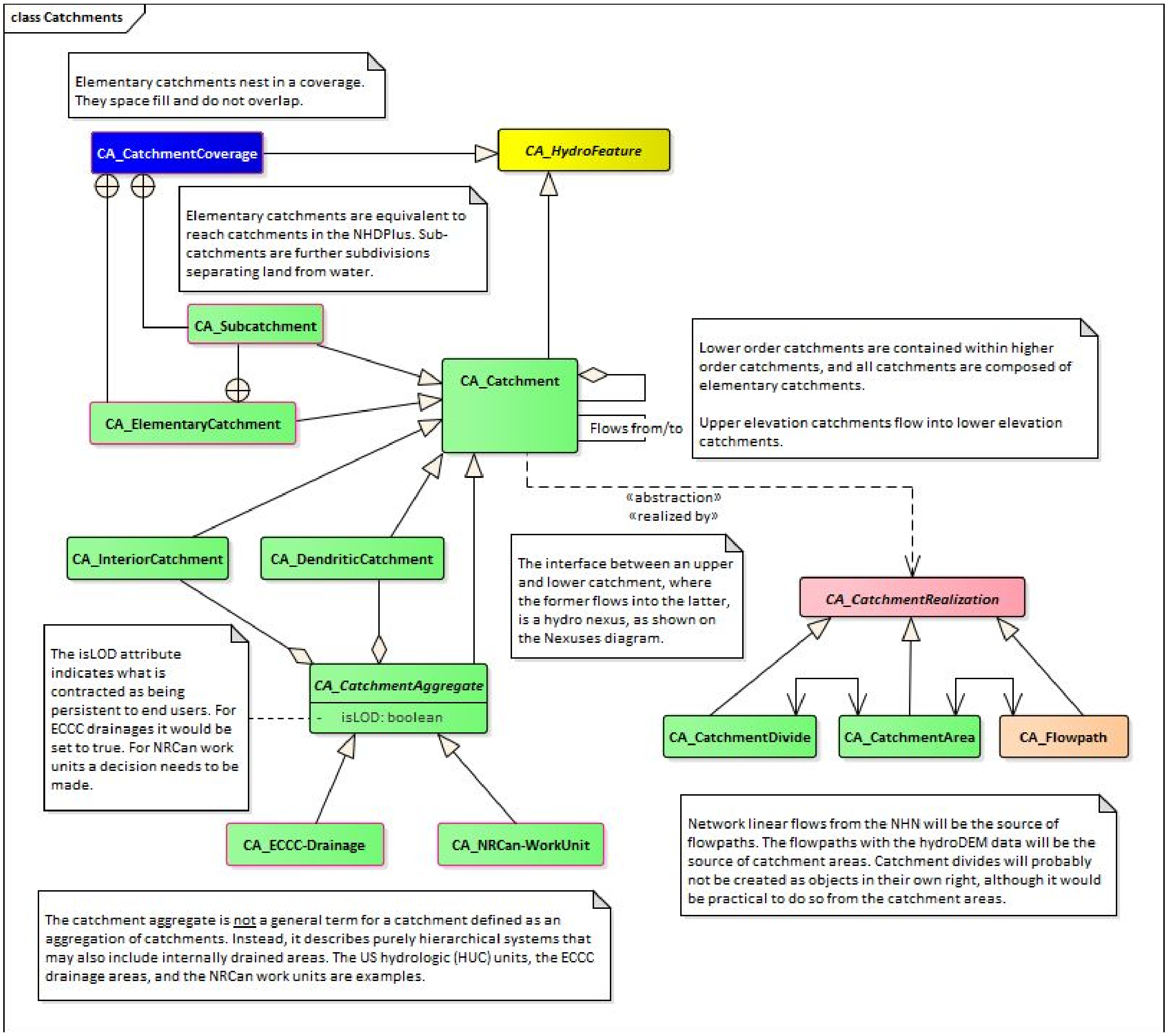

Figure 5: Catchment classes

As shown, the sub-catchments are nested in the elementary catchments, which in turn are nested in a catchment coverage. Elementary catchments may also be included in larger catchments. Larger catchments must be definable as an aggregation of non-overlapping, space-filling, elementary catchments.

CA_ECCC-Drainage and CA_NRCan-WorkUnit are specializations of the abstract superclass CA_CatchmentAggregate, which contains a boolean attribute, *isLOD,* that is not in HY_Features. This attribute indicates whether the hierarchy (in this case ECCC's or NRCan's) is to be considered as containing Linked Open Data. If it is, then publicly accessible components within the aggregate will have an LOD identifier. In the long term these two hierarchies should be merged. Statistics Canada has a third, closely related hierarchy, the [Standard Drainage Area Classification (SDAC) 2003] that like the ECCC hierarchy consists of drainage areas, sub-drainage areas, and sub-sub-drainage areas. Ideally ECCC, StatCan, NRCan and other federal government departments should all make use of the same hierarchy, in the same way that the HUC hierarchy has been widely adopted within the federal government of the United States.

Figure 5 also defines catchment areas and divides as catchment realizations, as is also the case with flowpaths. Catchment areas would be an initial geoprocessing objective using a DEM and the waterbody (and possibly the depression) features. The divides equate to the boundaries of the areas and would be directly important in the creation of the hydro DEM. However, once the data is processed, the resulting features appropriate for distribution are likely to be considered simply as catchments and their respective boundaries.

Figure 6 below shows that sub-catchments have a nested relationship with elementary catchment, but also an association with waterbody. From a geoprocessing perspective, the subcatchments are the result of intersecting elementary catchments with waterbodies that have polygonal geometry. This makes their existence somewhat scale dependent; however, for practical purposes the scale assumed for compilation or data distribution would apply here.

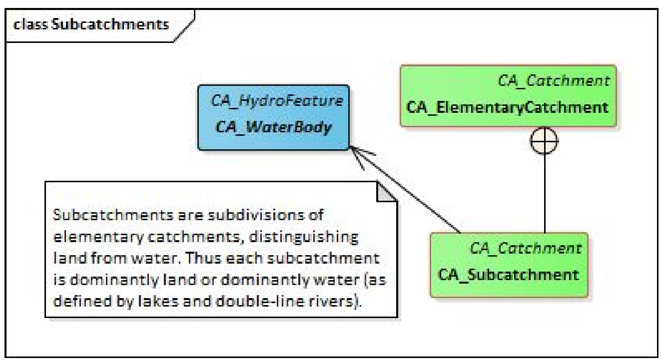

Figure 6: Subcatchment

4.2 Nexus and Hydro Location Classes

Nexus and hydro location constructs are the subject of Figure 7. CA_HydroNexus corresponds to HY_HydroNexus in HY_Features. However, three further nexus classes have been added in CHyF. CA_ContractedNexus is a specialization of CA_HydroNexus supporting the notion of a recognized, persistent, referenceable hydro nexus. Contracted nexuses would be used with catchment aggregates such as the ECCC drainage hierarchy, either as currently defined. or at some future point, a more detailed ECCC or government-wide version.

Whereas a hydro nexus represents an interface between adjacent catchments, a unary nexus refers to the source or upper end of a headwater (first order) stream. It has been introduced to allow for the full support of the hydro network schematically. CA_UnaryNexus and CA_HydroNexus are both specializations of CA_Nexus, which is an abstract superclass.

Hydro location is also displayed in Figure 7. All nexuses are realized by hydro locations. Hydro locations may also refer to other entities situated on or near a flowpath. CA_HydroLocation corresponds to HY_HydroLocation in HY_Features. Their codelists are the same and include the following:

- barrage
- bifurcation
- catchmentOutlet
- confluence
- dam
- diversionOfWater
- extractionWell
- fork
- hydrometricStation
- infiltrationWell
- injectionWell
- inletStructure
- intake
- outletStructure
- ponor
- pourPoint
- rapids
- referenceClimatologicalStation
- riverMouth
- sinkhole
- source
- spring
- waterfall
- weir

A decision will need to be reached whether to modify this list or to use a different list. For example, groundwater monitoring station is not included. Pour points are included, but drainage points are not; these are pour points slightly upstream from confluences that allow for the identification of unique pour points with individual catchments flowing into a hydro nexus. Hydro nexus is not included, although various versions of it are (bifurcation, confluence, fork, catchment outlet). Contracted nexus as a subclass could be removed and replaced with a boolean attribute under CA_HydroLocation. In HY_Features, HY_HydroLocation can be used with linear referencing. CHyF does not support linear referencing through explicit data structures. However, the same intent can be met through an upstream-downstream service, as discussed in section 7. Like Hy_HydroLocation, CA_HydroLocation will include a realizedNexus attribute to give the identifier for the nexus, in cases where hydrolocation refers to a catchmentOutlet, confluence or bifurcation for example.

Note: What is the difference between a fork and a bifurcation or between a confluence and a catchmentOutlet (and a riverMouth)? Is confluence a general term for junction or does it refer specifically to two segments in and one segment out, the reverse of a bifurcation? Also, we may have a hydro location that is both a source and a spring for example or a riverMouth and a confluence.

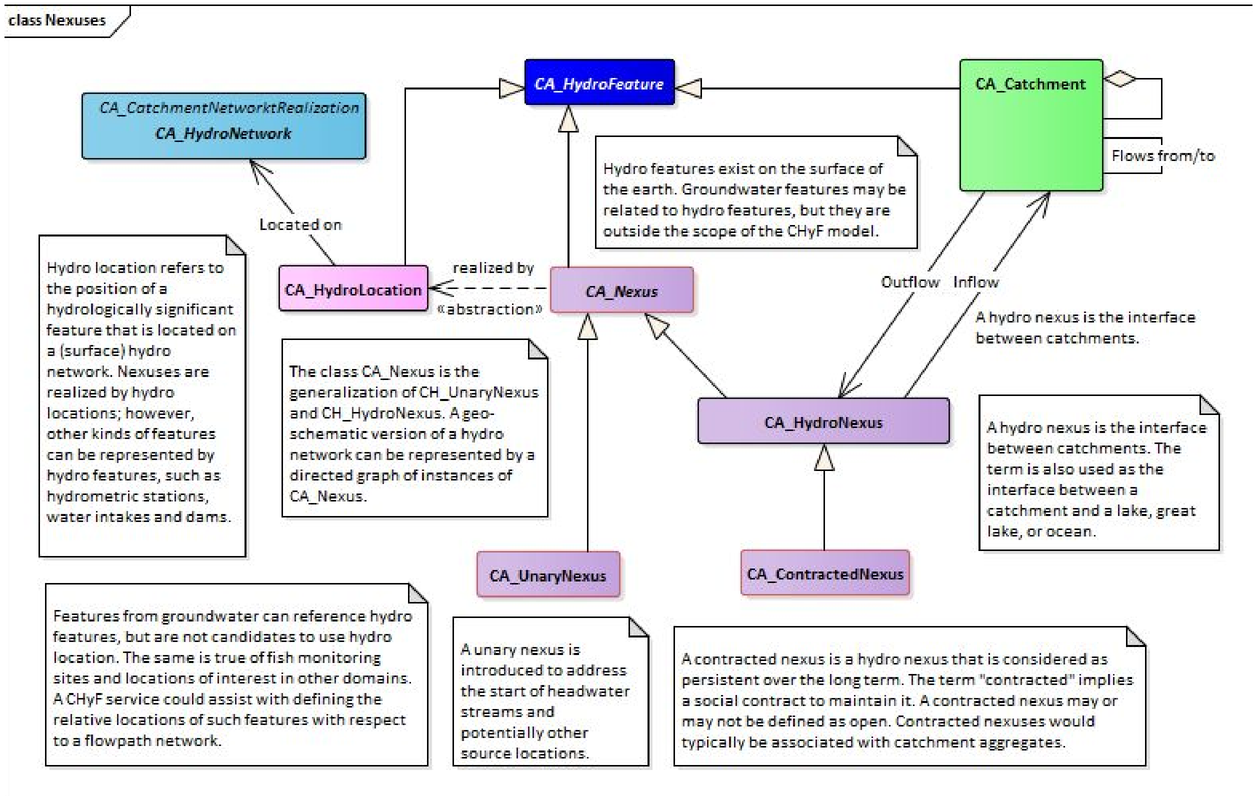

Figure 7: Nexus and hydro location

4.3 Hydro Network Classes

Figure 8 shows a number of different network constructs. A catchment network consists of catchments with a hydro nexus at each interface between catchments. In addition to direct instantiation, it is also realized by the class CA_NetworkRealization, which has two subclasses, CA_FlowpathNetwork and CA_HydroNetwork. Hydrographic networks are composed of water bodies, including lakes, rivers, canals, ditches, conduits and liquid waste impoundments. Channel networks contain channels and other depressions. Not specified in HY_Features, but of considerable importance, are flowpath networks, which are composed of flowpaths. Flowpath networks are structured such that they are compatible with the notion of directed, acyclic graphs; this will then make them suitable for use as the basis of upstream/downstream query services.

A main flowpath, also known as a mainstem or main stem, is a specialization of flowpath consisting of an ordered sequence of flowpaths. “Main stem” is discussed in HY_Features but does not appear in the formal (UML) model. Nevertheless, it is a useful construct of interest to a range of users.

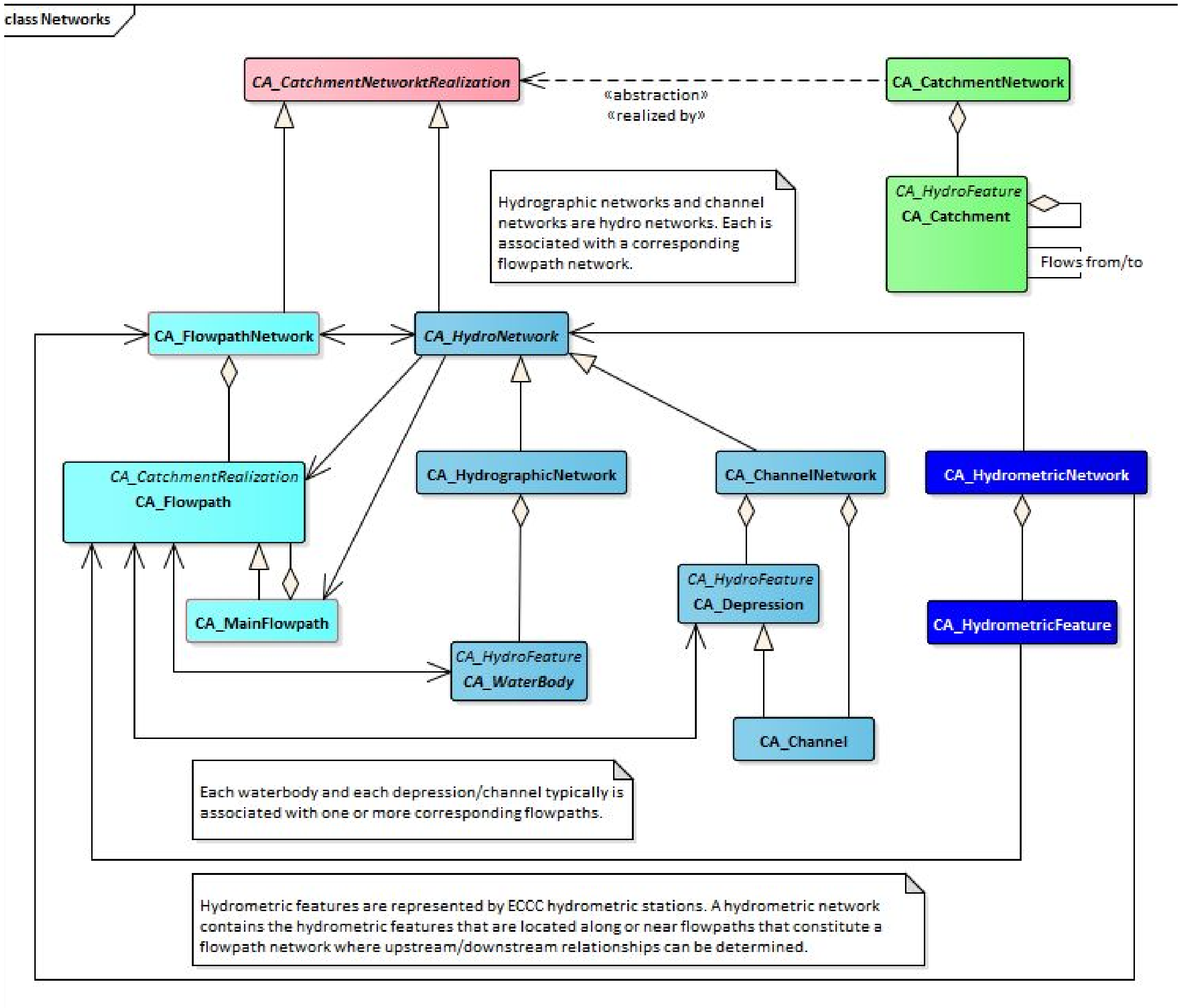

Figure 8: Networks

Also shown in Figure 8 are hydrometric network and hydrometric feature, the latter being identified with ECCC hydrometric stations. The stations are located along flowpaths. Since each station can be projected to a position on the nearest flowpath, upstream/downstream queries involving the stations can be made. For reasons of simplicity, associations between hydrometric network and hydro network and between hydrometric feature and waterbody are not shown.

4.4 DEM Related Classes

Figure 9 below describes hydro DEM classes. These are outside the scope of HY_Features, although they are related to some of the equivalent CHyF features, as shown.

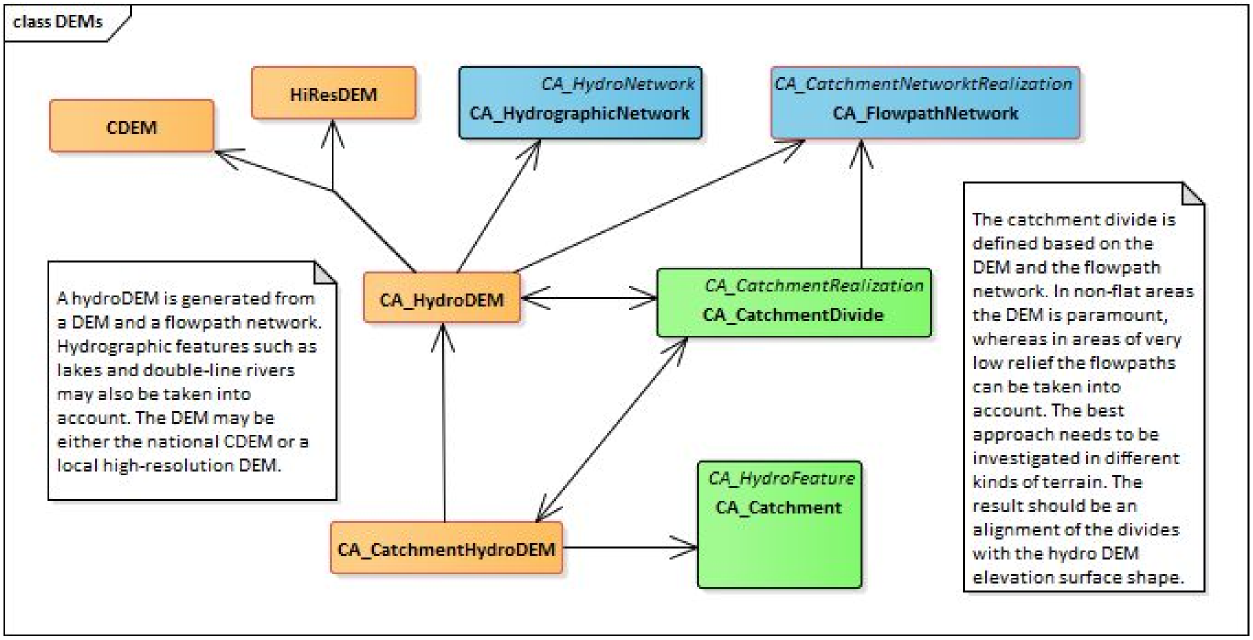

Figure 9: hydro DEM and divide

To create a hydro DEM, an existing DEM is used in concert with hydro features and their realizations as flowpath networks and catchment divides.The input DEM may be either the national CDEM product or a locally available high resolution DEM compiled used LIDAR or high-resolution imagery. The DEM may be represented as a point cloud or more typically as a gridded dataset. The flowpath network is embedded in some fashion in the hydro DEM. The same is true of catchment divides, which are formed from a preliminary hydro DEM and the flowpath network.

5 Flowpath Network Relationships

5.1 Stream Order and Main Flowpath

The most common stream ordering system is that defined by Arthur Strahler. Shown in the left-hand diagram below (after Wikipedia), it is often referred to simply as stream order. Robert Horton is responsible for a related ordering system, as shown on the middle diagram. Strahler order is readily determined moving from the headwater flowpath segments downstream. Horton order can then be derived moving in the opposite direction, following either stream name or longest length. A useful artifact of determining Horton order is the definition of the main flowpath (mainstem), shown in red on the right-hand diagram. John Hack developed another ordering scheme, which is similar to Horton order, but beginning at the outlet and moving upstream, as demonstrated on the right-hand diagram. It is sometimes referred as stream level. Hack order does not require that Strahler order be first calculated. CHyF supports these three kinds of stream ordering.

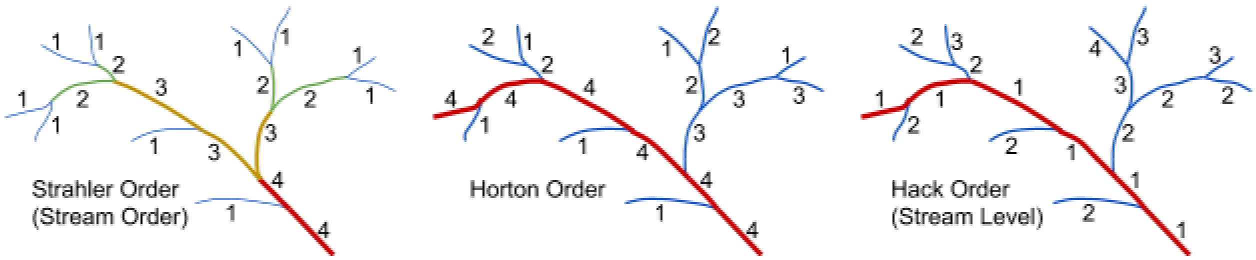

Figure 10: Stream order systems

Once either Horton order or Hack calculated is defined, the mainstem upstream from *any* arbitrary location on the network is defined. Horton order has been used to support generalization. For example in Figure 10, flowpaths could be removed with a Horton order of 1 or 2, and all others could be retained. The result would be a much simpler stream network that would also have much simpler catchments. The geometry of both the resulting network and the catchments could be simplified further through suitable algorithms (such as Douglas-Peucker) if desired. (Other approaches to generalization exist, but this one can be easily implemented.) Hack order has an advantage that order number is relatively invariant under different degrees of generalization. For example, a stream emptying into the ocean will always be of order 1.

The determination of both Horton order and Hack order requires moving upstream following the most important stream at each confluence. Importance could be defined by: (i) name, (ii) actual flow, (iii) flow accumulation as indicated by area, (iv) length, or (v) number of inflowing tributaries. Good arguments exist for all of these. Name is often correlated with actual flow, but flow accumulation grids are readily generated and length is simpler still. With CHyF, name, flow volume and total upstream network length, in that order, will be used as the basis for such ordering.

In addition to Strahler, Horton and Hack, other ordering systems may also be of interest. For example, Shreve order provides the number of upstream unary nexuses (equivalent to the number of first order streams) for a given stream segment. The Pfafstetter Coding System, which has been used in Europe and elsewhere, embeds topologic relationships in the codes for each flowpath segment and corresponding primary catchment. CHyF does not support these, but they could be added as services if there were sufficient interest.

5.2 Flowpaths at Points of Divergence

Flowpath networks typically form dendritic patterns, or other patterns such as trellis, rectangular, radial, parallel, etc. that are topologically equivalent to dendritic. In all such cases a confluence point serves as the intersection point of two incoming flowpaths and one outgoing flowpath. However, other patterns also exist. A fork may exist in a stream resulting in one incoming flowpath and two outgoing flowpaths. The fork may represent the point of initiation of distributaries, braids or flows around islands in large streams. In all such cases a main flowpath is designated with the other flowpaths specified as secondary flows. For many users such data is sufficient, so long as it is topologically structured as a network with a single flow direction on every segment and without any loops whereby water flow can start and end at the same place.

For some applications however a user may require that the network be topologically dendritic. This is the case for example for those wishing to convert the data to a raster form with the intent of using an eight-direction (D8) flow model to create flow direction and accumulation grids. Removal of the secondary flowpaths leads to a dendritic pattern and could be accomplished as a function of a web service. The same service could offer an alternative way of ensuring a dendritic pattern, creating flow gaps by removal of the top (upstream) metre or so of all secondary flows. Thus, so long as the data is topologically structured with all segments correctly oriented, no geometry change need be made to the flowpaths or their associated waterbodies as stored, even for those users who require a dendritic network.

5.3 Upstream - Downstream Relationships

nextDownID could be included as a flowpath attribute to enable traversal across the flowpath network. An argument against this is that in the context of a service, an indexed graph representing the flowpath network would make upstream/downstream query response highly efficient. So long as the data is topologically clean, the graph can be generated very quickly, mitigating the burden of managing such links. The links would not be visible to the user. Instead the user would make use of an upstream-downstream service that would be able to determine the relationships between flowpath segments as well as catchments. This is discussed further in section 7.

5.4 Flowpaths in Large Waterbodies

Connecting a large numbers of streams entering a lake can lead to massive sinewy structures consisting of nearly parallel, closely spaced flowpaths that can be kilometres long in large complex lakes. They guarantee connectivity, but at the cost of creating extremely thin elementary catchments that encapsulate each of these flowpaths. Arguably this does not matter, as the principal objective is to connect the flowpaths. However, others have considered different approaches that may be simpler. The Government of Ontario is currently experimenting with using bathymetry to define a nearshore boundary. In the absence of bathymetry a 100 m or 50 m buffer is an option. In either case the interior ring representing the nearshore limit is broken at the upstream end. The incoming flowpaths can then connect to this inner boundary line, which at the downstream end is connected to the outflow point. One option is to use subsurface channels in the bathymetry to connect inflowing streams to the nearshore inner boundary. Where there are no channels in evidence, either projection can be used, or the lake boundary itself can be treated in a similar fashion for the purpose of connectivity. The suggestion here is that this issue is worth further consideration. Discussion has recently begun between the Ontario Ministry of Natural Forests and Lands, and some of its partners related to management of the Great Lakes.

6 Catchments

6.1 Elementary Catchments and Subcatchments

Every catchment drains into a hydro nexus. In Figure 11 below a hydro nexus is shown at each flowpath confluence, as well as at the intersections of flowpaths with lake boundaries. In total eleven elementary catchments are demarcated, labelled with the letter A through K. “A” is a catchment, “B” (B1+B2+B3) is another catchment, etc. These elementary catchments correspond to the notion of reach catchments in the US NHDPlus.

A problem with them is that they are not particularly homogenous. B, D, F, G, and H contain both land and water, thus negating the value of such measures as average slope or elevation. From both hydrological and ecological perspectives, having an arbitrary percentage of water in an elementary catchment is problematic. They cannot be treated as hydrological response units (HRUs), nor as specific biomes. Consequently, interest has been expressed in subdividing them into subcatchments. The elementary catchment structure is retained, but further subdivision is available with inherently less variability in each resulting area.

Every undivided elementary catchment is considered as containing one subcatchment. Thus in Figure 11 the 20 subdivisions constitute 20 subcatchments, with the flow relationships listed on the right side of the diagram.

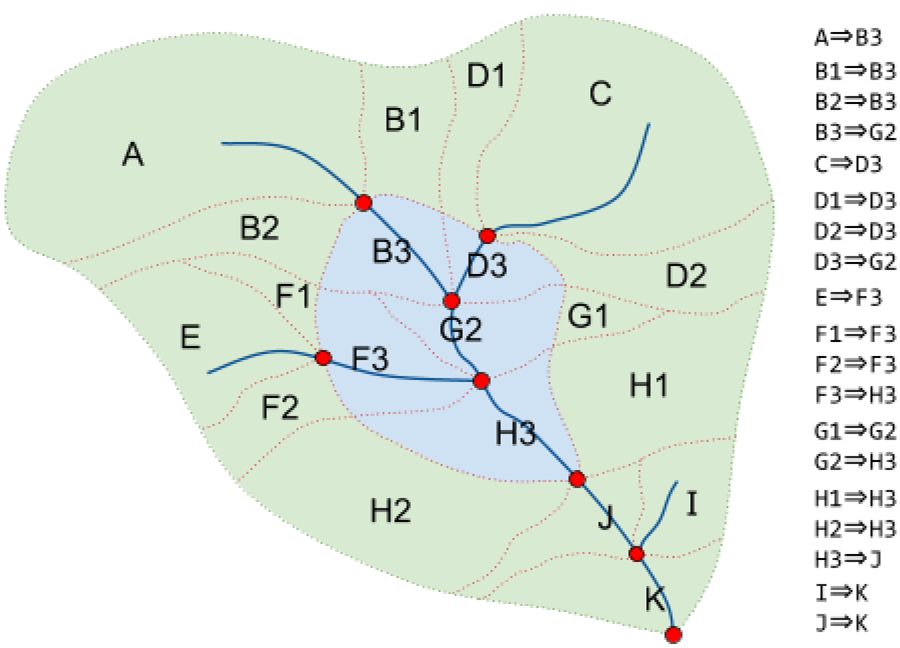

Figure 11: Elementary Catchments and Subcatchments

6.2 Hierarchical Catchments

Given a flowpath network, the catchments around each flowpath can be defined. Figure 12 shows a simple network on the left, as provided by the NHN. Elementary catchment boundaries are then generated, as shown in the middle figure. The diagram on the right shows the eight elementary catchments in eight areas of differing tones. Five of these are first-order catchments. Two second order catchments are present, one with a blue boundary and the other with a red boundary. A single third order catchment is depicted with a green boundary.

In all cases for `n > 1`, a catchment of order `n` contains:

- `2 to i`, where `i` is any positive integer `> 2`, catchments of order `n - 1`,
- `0 to j`, where `j` is any positive integer, catchments of order `n - 2`, `n - 3`, etc.,
- `0 to k`, where `k` is any positive integer, remnant areas that are bisected by a flowpath, that are elementary catchments in their own right, and that may be considered as of order `0`

With the exception of remnant (order `0`) elementary catchments, the catchments of a given order contain a flowpath network of the same order.

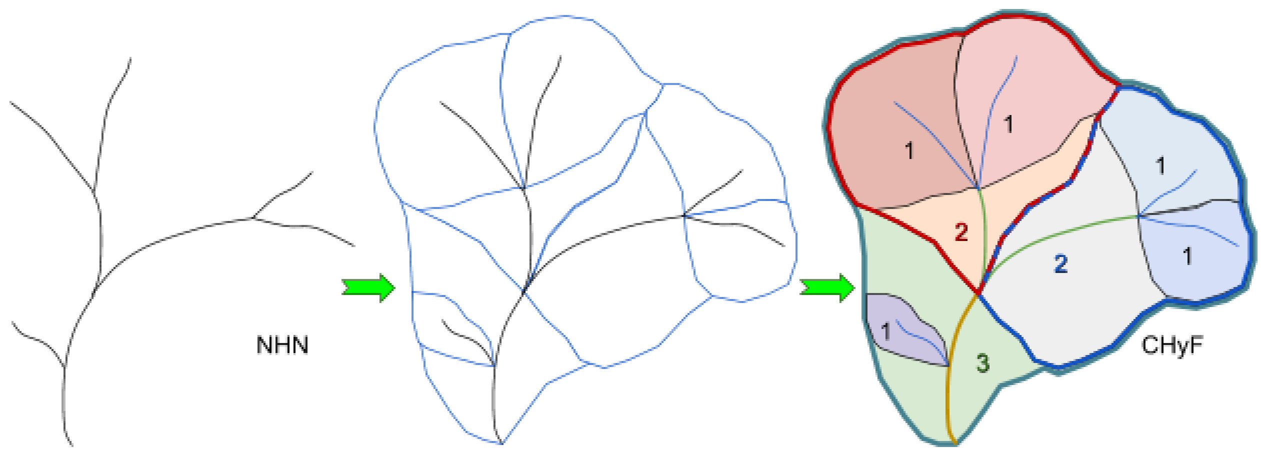

Figure 12: Flowpath network and corresponding catchment hierarchy

Nested catchments and their relationships (Figure 12) are readily defined if braids and distributaries can be ignored. This is accomplished by using only primary flowpaths. The distinction between primary and secondary flowpaths already exists in the NHN, but in general can be determined by considerations of length and central location in the absence of flow information.

6.3 Catchments Defined by Arbitrary Hydro Nexuses

Although not highlighted in Figure 12, each of the first-order streams begins with a unary nexus, which in a graph context can be considered a node of degree one, as only a single edge (flowpath) starts or ends at the node. The confluences are hydro nexuses, with each representing the interface between catchments. They are all of degree three, the simplest and most common case for flowpath confluences. In rare cases a hydro nexus is of order four, where three flowpaths and hence three catchments are inputs and one flowpath and its corresponding catchment are outputs. Other configurations are also possible.

One that is fairly common is a hydro nexus which when considered as a node is of degree two, with one inflow and one outflow. The hydro nexus may refer to a hydro location of interest such as a dam or weir. It may represent the proposed site for a new development or of an existing town. Figure 13 shows two hachured areas, with a yellow hydro nexus between them. If that hydro nexus were absent these two areas would define a single area defining the catchment for the included flowpath. With the hydro nexus present, two elementary catchments are formed as shown, with the upper one flowing into the lower one through the hydro nexus.

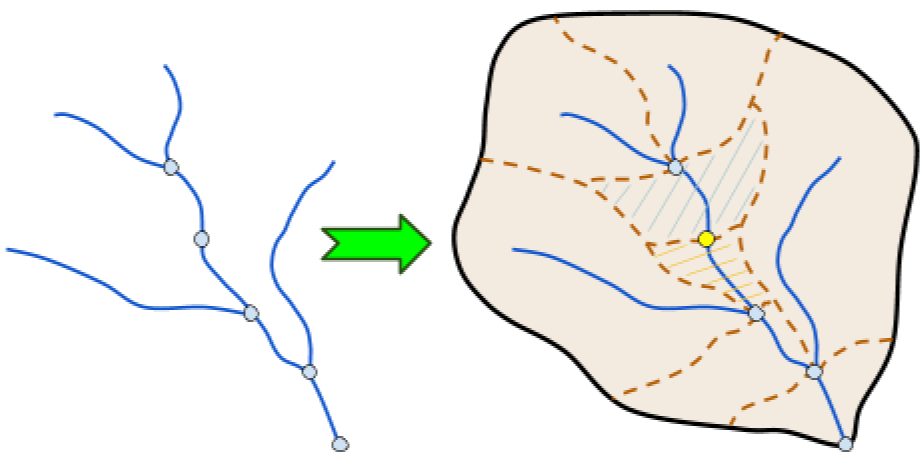

Figure 13: Catchments defined by arbitrary hydro nexuses

6.4 Interior Catchments

Interior catchments, also referred to as isolated catchments, may exist, as shown in Figure 14 below. on the left an isolated catchment is surrounded by a larger catchment. One option is to connect the flowpath in the isolation to nearby flowpaths, thus eliminating the isolation. On the right, we have a similar picture but in this case the small isolated catchment is adjacent to, and not contained within, its neighbour.

Here again a decision must be made as to whether to leave the small catchment isolated. Some users prefer that they be kept as isolated features, whereas other users prefer that they be integrated directly into the larger surrounding or adjacent catchments, including generating connections between the stream networks following depressions in the DEM. It may also be that the isolated area is not really isolated; subsurface flows or unmapped conduits may serve to connect the catchment. Instead of altering the basic data, it may be possible to meet varoius objectives using appropriate services.

The interior catchments in Figure 14 are simple, elementary catchments. They could be much more complex catchments containing higher order flowpath networks. So decisions as to how best to handle isolations could use order in a decision tree, along with other factors such as length, area, and/or distance to a nexus in an adjacent flowpath network.

3rd option: straight schematic connections for sink hole / under ground subsurface flow to a point on the network downstream where it is presumed to resurface. Coded as groundwater flow or conduit (for example the aqueduct running from Shoal Lake in Ontario to Winnipeg in Manitoba).

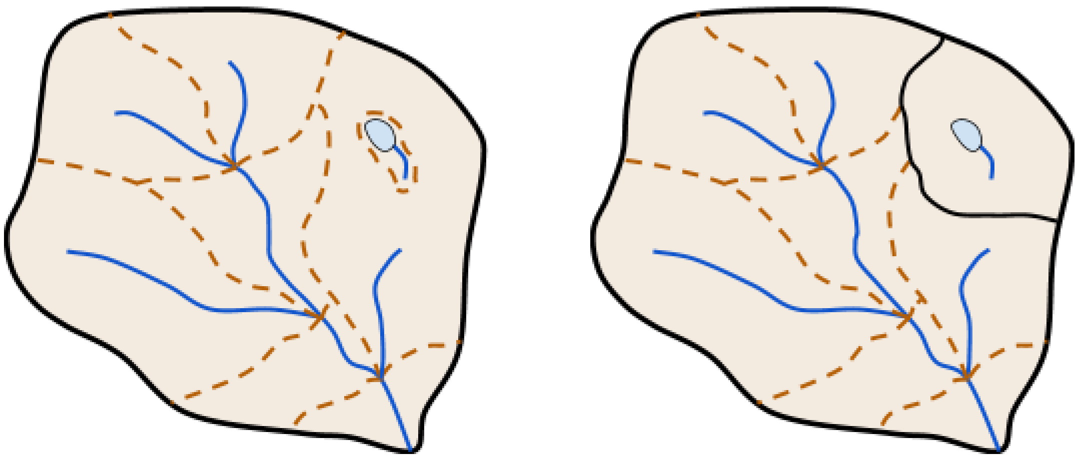

Figure 14: Interior catchments

6.5 Catchments in Areas of Indeterminate Flow

Prairie potholes (Figure 14) and other very flat areas are sometimes referred to as non-contributing areas. A better term would be areas of indeterminate flow. Unlike flat terrain in many arid regions, these areas may have a substantial amount of water or snow during much of the year. The flow direction may vary depending upon hydrostatic pressure in the water table caused by local rainfall patterns. In HY_Features a distinction is made between exorheic (externally drained) and endorheic (internally drained) situations, but neither of these is a good descriptor of these areas of indeterminate flow.

Further investigation is required to determine the best approach to catchment delineation in such areas. One approach may be to ignore elevation entirely and to make use of a line Voronoi approach based on nearby stream networks. This would lead to divides arbitrarily crossing waterbodies, but that might be acceptable in these situations.

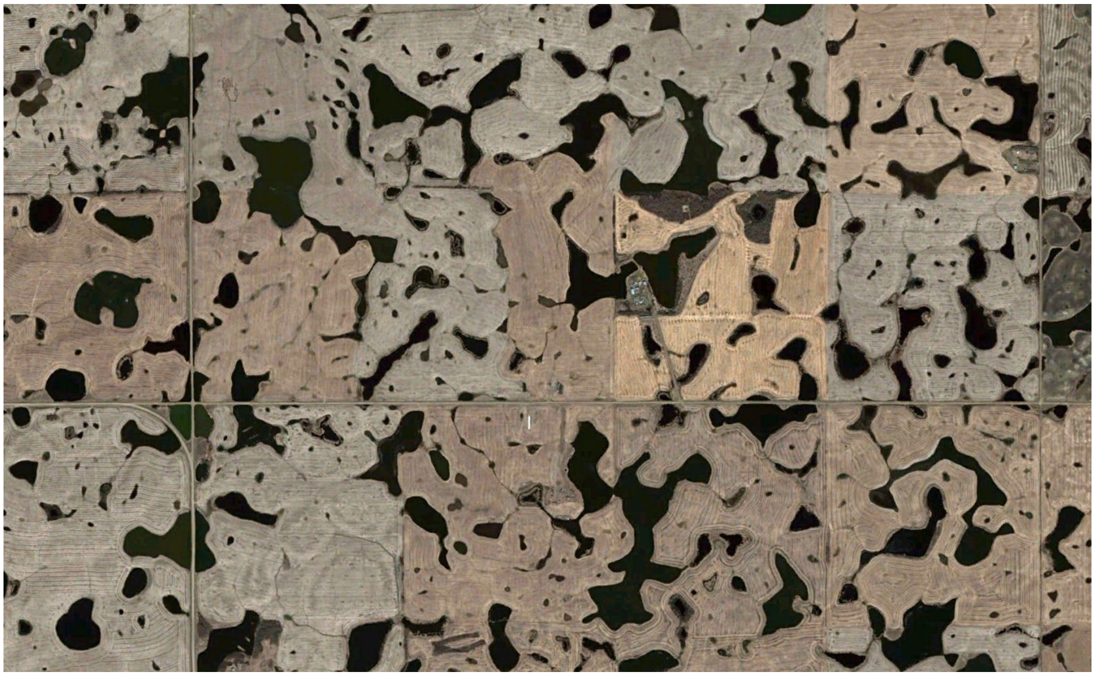

Figure 14: Prairie potholes in Saskatchewan

6.6 Catchments and Dragon Backs

In Figure 13 are two simplified shoreline examples of what has been called a dragon back boundary in the US. Consider the case on the left first. If these small remnant areas devoid of streams are adjacent to a typical lake, then they would be incorporated into catchments that would also include portions of the lake. In the case of the ocean or one of the Great Lakes, it is likely that they would be grouped with catchments covering very large areas of water. For typical lakes this need not be a problem, as subcatchments would be available to be able to distinguish land from water.

The diagram on the right shows a variation in which a flowpath is very short. The case can be made that very short flowpaths should be ignored; the same argument can be made with lakes that are under a certain size. Such arguments may carry more weight in areas of indeterminate flow, but in light of much higher resolution mapping becoming available, rules that would be applied universally must take resolution and scale into account. Generalization is always possible given the metrics and relationships that should be stored with each catchment and subcatchment.

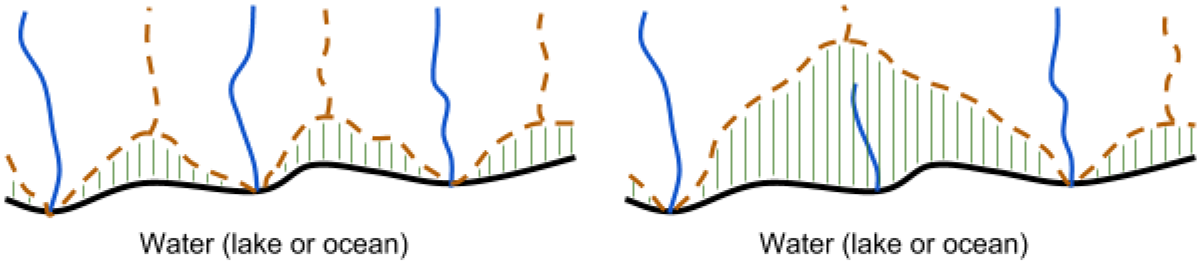

Figure 15: Catchments and Dragon Backs

6.7 Catchments and Distributaries

Distributaries exist where a hydro nexus acts as a fork with the resulting branches not reconnecting, as with braids. They are the typical drainage pattern found on deltas. One of the branches would be labelled as primary and the others as secondary, just as with braids. And as with braids the secondaries could be ignored during catchment delineation or they could be taken into account as shown in Figure 16. Normally the latter approach is preferred.

One issue with distributaries is that they are often located in area of very flat terrain, where the DEM may may not be helpful in determining the locations of catchment divides. As noted before, in such cases a line Voronoi or equivalent approach to catchment delineation will be required.

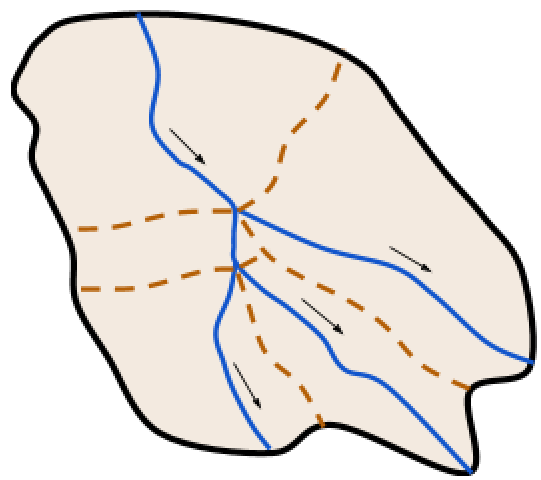

Figure 16: Catchments and distributaries

6.8 Catchments in Areas of Braided Streams

Braids create greater complexity. In a simple case, such as that shown in Figure 17 below, elementary catchments can be defined as described above. One of the braids would be considered as primary and the other(s) as secondary, as shown by the differently coloured segment in the figure. This allows for the mainstem to be designated and for a dendritic network to be defined.

Braids lead to a change in catchment relationships. At a typical hydro nexus, such as the one shown in cyan, two catchment flows into another catchment. However where braids occur, the reverse is true at the upper end of each braid. At the red hydro nexus one catchment flows into two.

If braids are considered as indeterminate or if the divides between them are ambiguous, then they may be ignored. In such a case, the divides that are drawn would cut across some of the braids. However, given that divides will normally be auto-generated, this situation is unlikely.

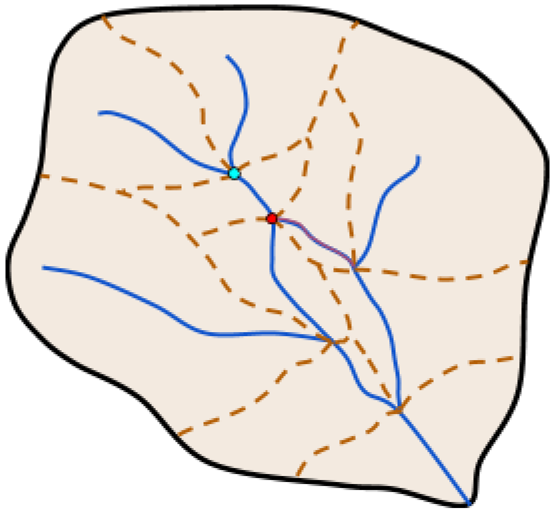

Figure 17: Catchments and braids

7 Events and Upstream/Downstream Services

A linear referencing system was originally specified as an option with the NHN; however, it was not used very much and so was eventually dropped. A combination of lack of interest and the potential for high maintenance were responsible. Nevertheless, it is easy to argue that events in watersheds or along stream networks need to be supported in some fashion. A dam for example can be considered as an event on a stream network. A contamination site on a stream or at an arbitrary location in a watershed may be thought of as an event. The same is true of a groundwater monitoring station.

Queries about such events can be answered through an upstream/downstream web service. Consider an event of any arbitrary type. It could be a feature as defined under hydro location or it could be something from another domain, as with a fish count monitoring site or the feature types noted above. Now assume that the the feature of interest has an LOD identifier and a geographic position (longitude and latitude or some other coordinate pair with a corresponding Spatial Reference System identifier (SRID)). The web service could be used with the LOD identifier and position as input, for one or more arbitrary features. The service would return distances upstream or downstream to/from contracted nexuses, or each other, or other arbitrary points on the network. The features would be projected onto the flowpath network, which would be stored internally as an indexed, directed graph with the length of each segment. The projection distance could also be returned. (If the query does not require actual upstream or downstream distances, another option is to use the relationship between the flowpaths and the elementary catchments with a point in polygon algorithm to obtain a similar result.) The reverse set of services could also be invoked: given a relative distance up or downstream, return the geographic position. Responses to any of these queries would be extremely quick.

Examples where this would be of interest include the following:

- Define what hydrometric stations are upstream from a given station,
- Provide the stations back as an ordered list or a set of ordered lists, where the stations fall on different upstream branches,
- Return downstream distances from one or more contaminated sites to the mouth of a river or to a city water intake,
- List in upstream order the features of arbitrary types located along the mainstem of a major river.

8 LOD, Predicates and Web Services

CHyF will be implemented using an LOD approach where practical. Linked data relates a subject (a feature) and an object (another feature) through a predicate. One of the forthcoming efforts will be to define the predicates of interest. Candidates are given in the two lists provided below. In a couple of cases terms are taken from existing open vocabularies. WML2 refers to the OGC and FGDC endorsed WaterML information model. DUL refers to the DOLCE+DnS Ultralite ontology.

From the Dimensionally Extended nine-Intersection Model (DE-9IM):

- *equals*

  `CA_Glacier-x` *`equals`* `CA_Glacier-y`
- *intersects* and its negation, *disjoint*

  `aquifer-x` *`intersects`* `CA_Catchment-y`

  `aquifer-x` *`disjoint`* `CA_Catchment-y`
- *touches*

  `CA_Waterbody-x` *`touches`* `CA_Waterbody-y`
- *contains* and its inverse, *within*

  `CA_Catchment-x` *`contains`* `CA_Catchment-y`

  `WML2:MonitoringPoint-x` *`within`* `CA_Catchment-y`

Additional predicates based on hydro requirements:

- *upstream-of* and its inverse, *downstream-of*

  `DUL:Place-x` *`downstream-of`* `DUL:Place-y`

  `DUL:Place-y` *`upstream-of`* `DUL:Place-x`
- *flows-into* (*touches* and *upstream-of*):

  `waterbody-x` *`flows-into`* `waterbody-y`

- *drains:*
  `CA_River-x drains CA_Catchment-y`
- *hydraulically-connects:*
  `hydrogeounit-x hydraulically-connects CA_Waterbody-y`
- *measures:*
  `hydrometric-feature-x measures CA_River-y`
- *near* (this could be expressed topologically if a delta is assumed):
  `hydrometric-feature-x near CA_Waterbody-y`

Negation is possible in all cases:

- not (….)
  `Not(aquifer-x intersects CA_Catchment-y)`

Further assessment may lead to the requirement for more predicates, but those given above constitute a good starting point. Using *contains*, *upstream-of* and *flows-into*, LOD triplets or equivalent could be defined for basic entities in the system such as elementary catchments, larger catchments, flowpaths, and waterbodies.

The predicates given above also provide the basis for a number of web services, which may or may not make use of LOD techniques. Because features can be represented by their LOD identifiers, queries such as the following could be answered, with an understanding of the underlying semantics left to the user but expressed here:

- Return the ESSS sub-sub-drainage areas for a series of wildfires in which they are located.
- Return the census counts in the watershed associated with a given named stream.

Such queries are in addition to those provided in section 7 above. The list of possible queries is large, so initially thought must be given to decide which would be of most interest for demonstration purposes.

9 Hydro DEM

A hydrologically conditioned DEM represents an idealized surface with elevation values consistent with hydrographic features draped across it. Catchment divides ideally appear as ridgelines and depressions, and channels in the DEM contain lakes and rivers. Figure 18 depicts a hydroDEM as a gridded surface with a river superimposed on the grid.

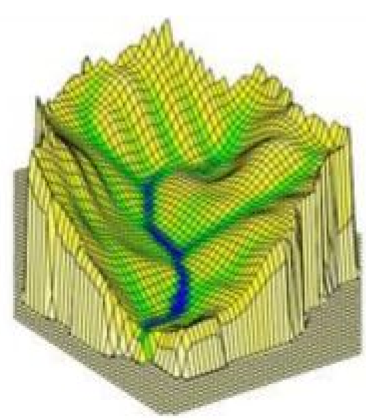

Figure 18: Gridded hydro DEM with superimposed river

Various issues must be taken into account in the construction of a hydro DEM.

- In very flat terrain, noise and a general lack of resolution may mask features such as depressions and divides.
- Such features may not have a measurable surface expression, regardless of level of detail.
- Pits or spikes as noise artifacts may be present.
- The depressions and channels in a DEM surface may be at variance with hydrographic features situated on the surface. This could involve simple offsets as well as differences in shapes and patterns.
- DEM data compilation techniques occlude subsurface flows, including for example culverts under roads that may be of considerable importance.
- On large lakes and double-line rivers the surface may in fact not be horizontal, although typical processing routines may make them so.

Pit removal is part of typical DEM processing to generate a hydro DEM. Lowering the elevation of hydrographic features and raising the elevation of divides (often referred to as building walls) are common practices as well, although the ways in which this can be done will make the resulting surface more or less at variance with what is actually present. Because in most cases the DEM is the original source of the divides, walls either would not be built or would be generated as only slightly enhanced divides. Cutting through roads where culverts or other subsurface drainages exist has been demonstrated, but this is not a widespread practice. Decisions about how best to handle these issues will need to be made.

10 National Hydro Network Model

The UML diagram in Figure 19 shows the key elements of the NHN that are relevant to CHyF. The full specification can be found here. It is provided here so that it may be compared with CHyF and Hy_Features.

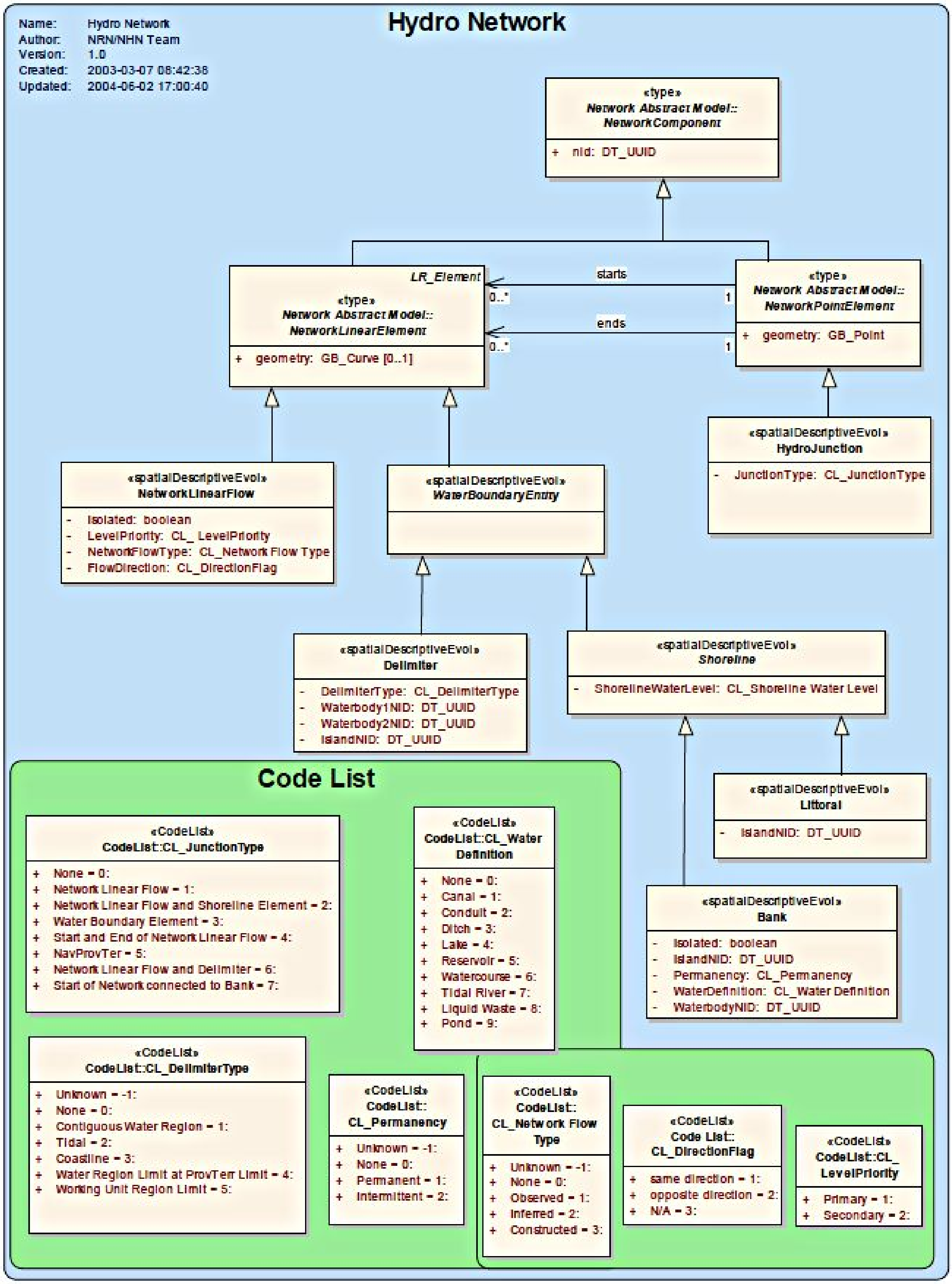

Figure 19: Hydro network hierarchy as modeled in the NHN

11 CHyF – HY_Features Crosswalk

Section 3 gave tables of CHyF feature definitions, and specified their relationships to feature types as defined in HY_Features and the NHN. What is provided here is a list of all feature type in CHyF and HY_Features, showing at a glance what feature types are in both, or just in one or the other.

CHyF Name	HY_Features Name	Comments
Catchment Model		Comparable feature types, but CHyF provides more detail
CA_CatchmentNework	--	Discussed in HyF, but not recognized in formal model
CA_Catchment	HY_Catchment	
CA_ElementaryCatchment	--	Reach catchments are of fundamental interest in the NHDPlus. Shown in many diagrams in HyF and also discussed.
CA_Subcatchment	--	This concept is of interest to some within the USGS. In HyF the term is used informally as a reference to elementary (reach) catchments; it does not appear in the UML or definitions.
CA_CatchmentCoverage	--	HyF notes that (reach) catchments compose a coverage, but the term does not appear in the UML or definitions.
CA_DendriticCatchment	HY_DendriticCatchment	
CA_InteriorCatchment	HY_InteriorCatchment	
CA_CatchmentAggregate	HY_CatchmentAggregate	
CA_ECCC-Drainage	--	Specific to Environment and Climate Change Canada

CA_NRCan-WorkUnit	--	Specific to Natural Resources Canada
CA_CatchmentArea	HY_CatchmentArea	Recommend implementing only as a service if at all
CA_CatchmentDivide	HY_CatchmentDivide	Recommend implementing only as a service
CA_CatchmentRealization	HY_CatchmentRealization	
CA_CatchmentNetworkRealization	--	
Water Containment Features		
CA_HydroNetwork	HY_HydroNetwork	
CA_HydrographicNetwork	HY_HydrographicNetwork	
CA_WaterBody	HY_WaterBody	In CHyF, several of the attributes defined in HyF will be dropped
CA_ChannelNetwork	HY_ChannelNetwork	May not be supported initially. This depends in part on whether depressions and channels can be consistently generated. Also, CHyF version may related just to DEM derived depressions and channels.
CA_Depression	HY_Depression	
CA_Channel	HY_Channel	
CA_Reservoir	HY_Reservoir	
CA_Flowpath	HY_FlowPath	CHyF and HyF have similar definitions, but with some differences related to how they are intended to be used.
--	HY_WaterEdge	
--	HY_LinearSegment	
--	HY_LongitudinalSection	Required for 3D representation; could be introduced if sufficient
--	HY_CrossSection	

--	HY_WaterBodyStratum	data becomes available to warrant their inclusion
--	HY_Water_LiquidPhase	Unlikely to be practical to implement at this time
--	HY_Water_SolidPhase	
CA_Ocean	--	Feature types deemed of interest in Canada, but out of scope of HyF
CA_GreatLake	--	
CA_Wetland	--	
CA_IceSnow	--	
CA_Glacier	--	
CA_Snowfield	--	
River Referencing		HyF uses explicit linear referencing, which is not supported in CHyF. Through LOD and services, the same capabilities can be provided by making use of fast algorithms and an indexed, directed, acyclic flowpath graph structure.
--	HY_RiverReferenceSystem	
CA_FlowpathNetwork	--	
CA_HydroLocation	HY_HydroLocation	
CA_Flowpath	HY_FlowPath	CHyF recognizes primary from secondary flowpaths. This distinction is not in the HyF model, although it is implied in the text.
--	HY_IndirectPosition	
Hydrometric Features		
CA_HydrometricNetwork	HY_HydrometricNetwork	
CA_HydrometricFeature	HY_HydrometricFeature	

Named Features Package		
CA_HydroFeatureName	HY_HydroFeatureName	
Hydrologic DEM		Out of scope of HyF
CA_HydroDEM	--	
CA_Catchment HydroDEM	--	
Cartography		
--	HY_CartographicRealization	Cartography might best be viewed as a separate subject.

12 Software Products

The products noted below all target catchment boundary generation.

12.1 COTS Options

Some commercial off the shelf (COTS) products that may provide of interest are as follows:

- ArcHydro - ArcGIS approach: http://gis.stackexchange.com/questions/116929/general-steps-to-create-watershed-boundary-in-arcgis-spatial-analyst
- AutoCAD Civil 3D also has something, but it may not be intended for the same scale: http://docs.autodesk.com/CIV3D/2013/ENU/index.html?url=filesCTU/GUID-23EC67A6-0084-4DAC-B58F-141155DB7E29.htm,topicNumber=CTUd30e8937
- FME provides a Voronoi Diagrammer transformer that may prove useful in flat terrain where the DEM is unlikely to be informative. This is being tested in Sherbrooke.

12.2 Open Source Options

Based on Whitebox / GoSpatial

Whitebox GAT: An open source tool with some promise:
https://whiteboxgeospatial.wordpress.com/2014/05/04/mapping-watersheds-in-whitebox-gat/
This work looking promising as a partial solution. He also has GoSpatial, a command line version of some key functions written in Go (a language from Google):
http://www.uoguelph.ca/~hydrogeo/software.shtml#GoSpatial

Also see his paper here:
https://www.researchgate.net/publication/286925102_The_practice_of_DEM_stream_burning_revisited or better yet here as a pdf:
https://www.researchgate.net/profile/John_Lindsay6/publication/286925102_The_practice_of_DEM_stream_burning_revisited/links/56700d4508aec0bb67c1710c/The-practice-of-DEM-stream-burning-revisited.pdf
This is very interesting, as stream burning is more complicated than one might initially assume. He appears to have some useful insights and tools.

Based on GRASS

GRASS/QGIS:
https://grasswiki.osgeo.org/wiki/Creating_watersheds

Also this based on GRASS:
http://gracilis.carleton.ca/CUOSGwiki/index.php/Generating_Wetness_Indices_for_Watersheds_in_GRASS

Based on TauDEM

This is out of Utah State University and has been used by the USGS (see below).

12.3 US Government Approach

The EPA developed Basins, now in version 4.1. “Version 4.1 of the Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) system builds on Version 4.0 and earlier versions of the system.” See here: https://www.epa.gov/exposure-assessment-models/basins-user-information-and-guidance and here for the user manual: https://www.epa.gov/sites/production/files/2015-07/basins-4-1-user-manual.zip I have a pdf version which may be easier to read. Look for “Delineation Plug-ins” to find relevant information. Note that this is based on “TauDEM (Terrain Analysis Using Digital Elevation Models) is a suite of Digital Elevation Model (DEM) tools for the extraction and analysis of hydrologic information from topography as represented by a DEM.” The internal link does not work, but this one does, from Utah State University: http://hydrology.usu.edu/taudem/taudem5/index.html.

12.4 BC Government Approach

The British Columbia government successfully pursued catchment delineation through two companies as noted below. In both cases vector approaches were employed that took into account both point cloud elevation data and connected hydrographic features as input. With flat terrain a line Voronoi approach was emphasized, whereas with moderate to steep terrain the elevation characteristics of triangles in a TIN structure were employed. A means of melding these two approaches was also developed.

Barrodale Computing:

http://www.barrodale.com/watertour The Barrodale work represented the first generation of automated catchment determination based on hydrography and elevation.

Refractions Research:

Subsequently, Refractions Research was employed to develop a similar, but independent approach, with the BC Freshwater Atlas (FWA) as the province-wide result. The NHN for BC was taken from the FWA.

12.5 Ontario Government Approach

What follow is from a comment by John Gaiot of the Ontario Ministry of Natural Resources and Forestry.

A tool also used by USGS and Ontario historically for hydro DEM enforcement was ANUDEM out of Australia. A simplified version of ANUDEM was also incorporated into ESRI ArcGIS known as the "Topo to Raster" function.
http://fennerschool.anu.edu.au/research/products/anudem-vrsn-53
http://pro.arcgis.com/en/pro-app/tool-reference/spatial-analyst/how-topo-to-raster-works.htm

Some limitations are also documented by ESRI (see link above). Ontario in particular has experienced several shortcomings including but not limited to: the creation of artificial berms (or raised streams) particularly when working with coarse contour based elevation sources; the surface tends to be under/over estimated in the smoothing algorithm; the difficulty to reproduce repeatable identical results between overlapping tiles; and the problem of a spot update impacting the results of the entire enforced DEM (a small change in the raw data causes minute changes to the entire enforced DEM tile where realistically there should be no change - therefore this makes seamless updating very difficult to perform).

Because of these findings, ANUDEM and "Topo to Raster" are no longer used by Ontario. In Ontario, a custom approach has been developed known as the Spot Burning technique which is embedded in the MNRF Terrain Processing tools. It is similar to Arc Hydro's AGREE enforcement method but can handle larger processing areas, minimizes the 'trenching effect' where possible, and can be seamlessly merged with adjacent processing areas. It also leverages the same stream grid component of the Enhanced Flow Direction method for complete hydrology compliance in the derived DEM, flow direction and watershed outputs. Note: Ontario is licensing these tools as Open Source software under the GNU License Agreement standard, and is expected to be made available for download from Land Information Ontario in 2018.