

OGC® WaterML 2

***Part 3 - Surface Hydrology Features (HY_Features) -
Conceptual Model***

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i. Abstract

The OGC Surface Hydrology Features (HY_Features) standard defines a common conceptual information model for identification of specific hydrologic features independent of their geometric representation and scale. The model describes types of surface hydrologic features by defining fundamental relationships among various components of the hydrosphere. This includes relationships such as hierarchies of catchments, segmentation of rivers and lakes, and the hydrologically determined topological connectivity of features such as catchments and waterbodies. The standard also defines normative requirements for HY_Features implementation schemas and mappings to meet in order to be conformant with the conceptual model.

The HY_Features model is based on an abstract catchment feature type that can have multiple alternate hydrology-specific realizations and geometric representations. It supports referencing information about a hydrologic feature across disparate information systems or products to help improve data integration within and among organizations. The model can be applied to cataloging of observations, model results, or other study information involving hydrologic features. The ability to represent the same catchment, river, or other hydrologic feature in several ways is critical for aggregation of cross-referenced or related features into integrated datasets and data products on global, regional, or basin scales.

ii. Keywords

The following are keywords to be used by search engines and document catalogues.

ogcdoc, OGC document, hydrology, feature, identification, conceptual model, UML, implementation standard.

iii. Preface

This standard defines the HY_Features common hydrologic feature model for use in identification of features as specific kinds of hydrologic features. It is intended to be used to document and share information about features that are the subject of hydrologic studies and reporting for a range of applications. HY_Features was originally commissioned to link hydrologic information across the scientific and technical programs of the World Meteorological Organization (WMO), and to assist WMO Members in discovering, accessing, and utilizing hydrologic data from different sources.

This standard is also intended to support the need for governance and guidance by national and international authorities. Aspects of the standard that support this goal are 1) canonical form, 2) implementation neutrality, 3) conformity to internationally recognized geographic information standards, and use of semantics inferred from terminology endorsed by the WMO and the UN Educational, Scientific and Cultural Organization (UNESCO).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. The Open Geospatial Consortium shall not be held responsible for identifying any or all such patent rights.

Recipients of this document are requested to submit, with their comments, notification of any relevant patent claims or other intellectual property rights of which they may be aware that might be infringed by any implementation of the standard set forth in this document, and to provide supporting documentation.

iv. Submitting organizations

The following organizations submitted this Document to the Open Geospatial Consortium (OGC):

- U.S. Geological Survey (USGS), USA
- Federal Institute of Hydrology (BfG), Germany
- CSIRO Land and Water, Australia
- Bureau of Meteorology, Australia
- Metalinkage, Australia
- French Geological Survey (BRGM), France
- University of Texas at Austin, USA
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vi. Changes to the OGC® Abstract Specification

The HY_Features conceptual model, described in this standard, references concepts defined in the OGC Abstract Specification (OGC AS). Conformance to the OGC AS may be achieved via specialization of the relevant concept. An example of this kind of conformance is a geographic feature specialization that carries specific hydrologic feature attributes and associations. Conformance may also be achieved by asserting a correspondence or analogy between HY_Features concepts and OGC AS concepts. For example, the river reference system for referencing positions along a nominal flowpath corresponds to linear referencing along any linear feature element. This standard requires no changes to the current version of the OpenGIS Abstract Specification.

Chapter 1. Scope

This OGC Implementation Standard defines a common conceptual feature model for use in identification of features as typical features of the hydrology domain using established models and patterns in use in the Hydrology domain and endorsed by WMO and UNESCO such as those documented in the "International Glossary of Hydrology".

This standard, along with expected future implementations of this conceptual model, will form the third part of an intended 'OGC WaterML 2' suite of standards that groups water-related OGC standards. Following *Part 1: Timeseries*, *Part 2: Ratings, Gaugings and Sections*, this standard is titled *Part 3: Surface Hydrology Features Conceptual Model*.

This document introduces the HY_Features conceptual model only. The normative model is a machine-readable UML artifact published by the OGC in conjunction with this document at: **[insert URL here]**. Clause 7 of this document presents requirements classes (ways of conforming to the conceptual model) and requirements for model implementations to meet in order to be considered conformant with the conceptual model. Conformance classes indicating how to demonstrate conformance to requirements are presented in Annex A.

Future standards documents in this series are expected to specify particular implementations of the conceptual model. For example, an OWL/RDF implementation will define machine-processable entities and relationships in the OWL schema language that implement the HY_Features conceptual model elements. HY_Features implementations are expected to support documentation and discovery of data as well as aid data transformation efforts. For example, a discovery service such as a catchment catalog might use HY_Features concepts to index services that provide differing catchment representations as well as related water quality and quantity observations. A catalog client could then use the index for automated analysis and data product generation.

The initial scope has been defined by the WMO Commission for Hydrology (WMO-CHy): to facilitate data sharing within the hydrologic community of the WMO Member countries and to improve the quality of data products based on these data by defining hydrologic features to convey their identification through the data processing chain "from measurement to hydrological information" [\[8\]](#).

To enable semantic interoperability of hydrologic data and services, it is necessary to agree on common concepts and methods. The HY_Features model was developed in order to formalize concepts and relationships of hydrologic and hydrographic features using the WMO/UNESCO "International Glossary of Hydrology" as a starting point. One of HY_Features main objectives is to provide a standard terminology for description of relationships between hydrologic features that can be used to implement data transfer formats. However, this conceptual model should be seen as a building block toward a hydrographic data interchange standard, but such a standard would require additional efforts.

HY_Features is meant to support linking data products across differing applications and jurisdictions. To enable this, the concept of a holistic catchment is defined and "hydrology-specific realizations" of the catchment concept are modeled as typical hydrologic features. This allows a particular catchment to be represented in different feature data products for different purposes while still retaining its identity.

The HY_Features model provides a basis for common and stable references that identify hydrologic features in a wide variety of applications:

- to link hydrologic observations to their feature-of-interest, e.g. link a streamflow observation to the river or catchment being observed,
- to allow aggregation of cross-referenced features into integrated datasets and data products on global, regional, or basin scales,
- to enable systems to unambiguously link data between systems and domains,
- to enable cross-domain or multi-discipline services to communicate through reference to standard concepts.

While HY_Features is intended to support a wide variety of applications, it is narrowly focused on surface water hydrographic features. As such, nuances of waterbodies and storages such as glaciers, snowfields, and wetlands are left to future work. Additionally, temporal aspects of hydrologic features are not addressed in this standard and would be expected to be handled by implementations using HY_Features classes for feature identification. Finally, as this standard precedes expected encoding standards, implementation details, such as the structure and handling of feature identifiers are out of scope.

This standard defines a conceptual model (normative) containing feature type definitions that conform to the OGC General Feature Model (GFM) (ISO 19101:2002 and ISO 19109:2006), expressed in the Geographic Information Conceptual Schema Language (ISO 19103:2005) using the Unified Modeling Language (UML). The GFM is a meta-model developed as a general framework for features and their properties in the context of geographic information. Feature types specific to an application domain are defined as instances of the general feature metaclass with their own sets of typical characteristics (property types and constraints) such as attributes, associations, or operations.

As shown in [Figure 1](#), the HY_Features conceptual model defines instances of the general feature metaclass specific to the hydrology domain. A general HY_HydroFeature type is defined to carry properties such as identifier and name that all hydrologic features should have. Specific feature types are then derived from HY_HydroFeature to reflect different aspects of hydrology and carry properties specific to each aspect. [Figure 1](#) also illustrates that HY_Features features can fill the role of features-of-interest or sampling features for hydrologic observation data conforming to the Observation and Measurement (O&M) model (ISO 19156:2011) or to hydro-specific O&M profiles such as in the OGC WaterML 2' suite of water-related standards.

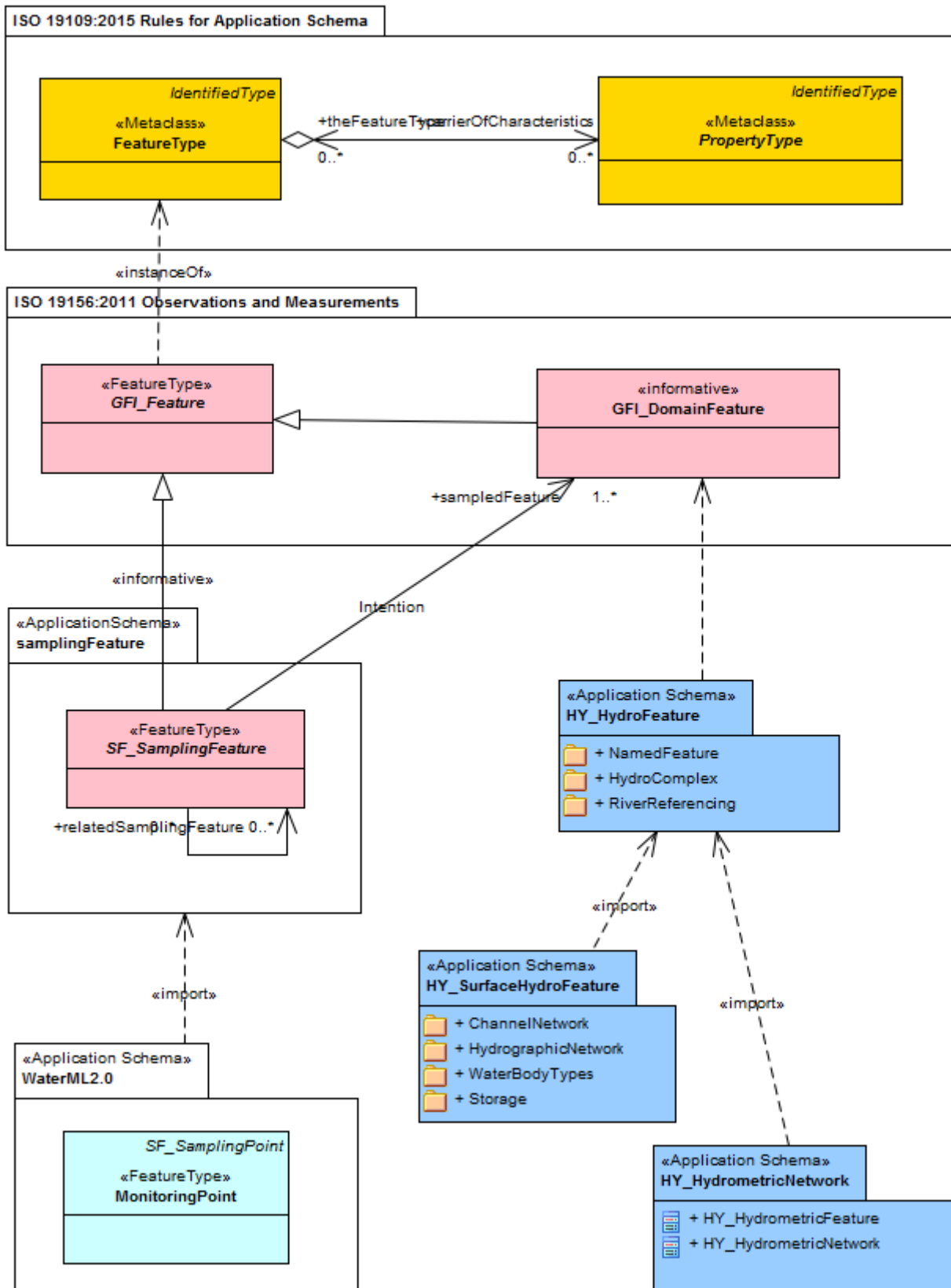


Figure 1. HY_Features in the context of the OGC Abstract Specifications

Chapter 2. Conformance

This standard defines a conceptual model for hydrologic features and their fundamental relationships. Requirements for conformance with the conceptual model are defined for two types of implementation targets: a) implementation schemas for representation of hydrologic data or b) implementation mappings between terms or concepts from two or more other existing hydro data schemas based on common intermediary HY_Features concepts. Any conformant implementations are required to satisfy the requirements defined in Clause 7 of this document for the requirements class(es) with which they assert conformance. This is true whether the implementation is explicit in the case of a schema (such as an OWL/RDF ontology or XML schema) or implicit in the case of common concepts for a schema mapping (such as an XSLT rule). The accuracy or detail with which an external term is mapped to a HY_Features common concept is beyond the scope of this standard, as is specification of a particular concept mapping methodology.

Annexes C-G of this document provide, nevertheless, informative mappings to and from HY_Features for the following hydro data models:

- Australian Hydrological Geospatial Fabric (AHGF) [\[11\]](#),
- USGS National Hydrography Dataset Plus (NHD Plus) [\[10\]](#),
- INSPIRE Hydrography theme [\[2\]](#),
- French National Service for Water Data and Reference-dataset Management (SANDRE) [\[12\]](#),
- Canadian National Hydrography Network (NHN) [\[13\]](#)

These mappings are intended to provide a general understanding of the correspondence between HY_Features concepts and existing conceptual / physical models. They are informative with respect to any future mapping implementations.

Conformance of implementation targets with this standard shall be verified using all the relevant tests specified in Annex A (normative) of this document. The framework, concepts, and methodology for testing, and the criteria to be met to claim conformance are specified in the OGC Compliance Testing Policies and Procedures and the [OGC Compliance Testing web site](#).

All requirements-classes and conformance-classes described in this document are owned by the HY_Features standard.

Chapter 3. References

The following normative documents contain provisions that, through reference in this text, constitute provisions of this document. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. For undated references, the latest edition of the normative document referred to applies.

OGC Abstract Specification Topic 1, Feature Geometry
(aka ISO 19107:2003, Geographic Information — Spatial schema)

OGC Abstract Specification Topic 2, Spatial referencing by coordinates
(aka ISO 19111:2007, Geographic Information — Referencing by coordinates)

OGC Abstract Specification Topic 5, Features
(aka ISO 19101:2002, Geographic Information — Reference Model)

OGC Abstract Specification Topic 11, Metadata (aka ISO 19115-1:2014, Geographic Information — Metadata — Fundamentals)

OGC Abstract Specification Topic 19, Geographic information - Linear referencing (aka ISO 19148:2012, Geographic Information — Linear referencing)

OGC Abstract Specification Topic 20, Observations and Measurements (aka ISO 19156:2011, Geographic Information — Observations and Measurements)

ISO/TS 19103:2005, Geographic Information — Conceptual schema language

ISO 19108:2006, Geographic Information — Temporal schema

ISO 19109:2006, Geographic Information — Rules for application schemas

ISO 19133:2005, Geographic Information — Location-based services — Tracking and navigation

Chapter 4. Terms and Definitions

This document uses the terms defined in Sub-clause 5.3 of [OGC 06-121r8], which is based on the ISO/IEC Directives, Part 2, Rules for the structure and drafting of International Standards. In particular, the word SHALL (not "must") is the verb form used to indicate a requirement to be strictly followed to conform to this standard.

For the purposes of this document, the following additional terms and definitions apply.

4.1. application schema

Conceptual schema for data required by one or more applications [ISO 19101]

4.2. boundary (line)

Geometric representation of a (catchment) boundary, usually a geometric composite curve.

NOTE

This definition references the definition of a *divide* described as summit or boundary line [9].

4.3. catchment

A physiographic unit where hydrologic processes take place. This class denotes a physiographic unit, which is defined by a hydrologically determined outlet to which all waters flow. While a catchment exists, it may or may not be clearly identified for repeated study.

NOTE

This approach considers the catchment concept to be the basic unit of study in hydrology, water resources management, and environmental reporting. The approach is meant to be holistic, referring to the continuous interaction of surface and subsurface waters within a catchment, even if a particular representation of the catchment refers to only surface or subsurface aspects of the catchment. Special subtypes such as drainage basin and groundwater basin may be defined with a particular application.

The synonymous use of the terms catchment and catchment area in the WMO/UNESCO International Glossary of Hydrology (which is the key reference for the definitions in the HY_Features model) does not clearly distinguish between the catchment concept and its geometric representations such as catchment area, nor between catchment and its possible specializations like drainage basin and groundwater basin.

To satisfy the need for a both a holistic definition of catchment and various refinements of it, the catchment feature type is refined by defining feature types that reflect distinct perspectives on the holistic catchment concept. In this standard, this type of refinement is referred to as hydrology-specific catchment realization. Also see clause 5.4 of this standard on the use of WMO terminology.

4.4. catchment area

Two-dimensional (areal) hydrology-specific realization of the holistic catchment. Topologically, the catchment area can be understood as a face bounded by catchment divide and flowpath edges. The concept of a face bounded by edges is described in detail in the ISO topology model [ISO19107]. The catchment area is usually represented as a geometric surface, and the measure of the catchment area may be denoted as surface area.

4.5. catchment divide

One-dimensional (linear) feature that is a hydrology-specific realization of the holistic catchment. Topologically, catchment divide can be understood as an edge bounded by inflow and outflow nodes. The concept of an edge bounded by nodes is described in detail in the ISO topology model [ISO19107]. The catchment divide is usually represented as a geometric curve, or as a polygon ring feature.

4.6. catchment network (topology)

Edge-node topology pattern of a set of catchments connected by their hydro nexuses. The topology pattern is derived from flowpaths, but ultimately reflects the inferred hydrologic connectivity between catchments and their hydro nexuses whether or not corroborated by geometric representations.

4.7. (internal) catchment topology

Topology pattern between hydrology-specific realization of a particular catchment. Example: Catchment area associating its catchment divide and the draining flowpath. This could include subsurface and atmospheric volumes, surficial catchment area, network of drainage channels and/or waterbodies, a linear flowpath, and an outlet (and possible inlet) node.

4.8. channel

Natural or artificial waterway, clearly distinguished, which periodically or continuously contains moving water, or which forms a connecting link between two bodies of water [9].

4.9. channel network

Connected set of depressions and channels that continuously or periodically contain water.

4.10. cross section (of a stream)

Section of a stream at right angles to the main (average) direction of flow [9].

4.11. cross section (of a stream bed)

transversal section of a stream bed in a vertical plane. This definition references the definition of a *bed profile* describing the shape of a stream bed in a vertical plane [\[9\]](#).

4.12. data

Documented value of some characteristics of a real-world phenomenon.

4.13. data set (also dataset)

Data compiled and arranged into a set. Used in its concatenated form to indicate a specific dataset, or as data set, for non-specific sets of data.

4.14. data product

Data set compiled for a specific purpose, e.g. for global dissemination using Web services.

4.15. dendritic catchment

Catchment in which all waters flow to a single common outlet. A dendritic catchment is permanently connected to others in a dendritic (tree) network, the most common *drainage pattern* of streams ultimately flowing into the ocean after joining together at confluences into larger and larger streams.

4.16. depression

Landform lower than the surrounding land and partially or completely closed that is able to but does not necessarily contain water.

4.17. domain feature

Feature of a type defined within a particular application domain. [ISO 19156].

4.18. endorheic (drainage)

Draining [ultimately] into interior catchments [\[9\]](#).

4.19. exorheic (drainage)

Draining [ultimately] into the ocean.

4.20. feature

Abstraction of real-world phenomena [ISO 19101].

4.21. flowpath (also flow path)

One-dimensional (linear) feature that is a hydrology-specific realization of the holistic catchment. Topologically, flowpath can be understood to be an edge bounded by inflow and outflow nodes, and associated with left-bank and right-bank sub-catchment faces. The concept of an edge bounded by nodes is described in detail in the ISO topology model [ISO19107]. The flowpath is usually represented as a geometric curve.

	A flowpath feature may form the "main stem" of the stream network flowing to the catchment outflow node from its inlet node(s).
NOTE	With respect to the river referencing system described in this standard, the flowpath corresponds to the linear element 'that serves as the axis along which linear referencing is performed' as described in the OGC Abstract Specification Topic 19, Linear referencing [aka ISO 19148].

NOTE 3: Hydrologically, the flowpath references the *path line* __ described by a moving particle of water [9].

4.22. flow line (also flowline)

Geometric property of a flowpath, usually a geometric curve.

NOTE	This definition references the definition of a <i>path-line</i> [9] through using the synonym <i>flow line</i> to express the geometric property of a flowpath.
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4.23. hydrographic network

Aggregate of rivers and other permanent or temporary watercourses, and also lakes and reservoirs [WMO, 2016].

NOTE	Not to be confused with the network of hydrological stations and observing posts.
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4.24. hydrologic complex

Collection of distinct hydrologic features forming a hydrologically connected system where the union of one or more catchments and a common hydro nexus is realized by multiple complexes of hydrology-specific topological elements. For example, a single catchment may be hydrologically realized as a face-edge complex of subcatchment areas and divides, or an edge-node network of flowpaths and hydro nexus nodes, and also as a dendritic edge-node network of either waterbodies or containing channels.

4.25. hydrologic feature

Feature of a type defined in the hydrology domain, whose identity can be maintained and tracked through a processing chain from measurement to distribution of hydrologic information.

4.26. hydro(-logic) location

Any location of hydrologic significance located "on" a hydrologic network that is a hydrology-specific realization of a hydrologic nexus. In a given dataset, hydro locations may or may not have an associated hydrologic nexus and associated catchment features. In such cases, hydro locations would typically be linearly-referenced to a defined set of catchments' flowpaths. Topologically, a hydro-location can be understood as an inlet or outlet node located at the end of a flowpath edge. The hydrologic location is usually represented as a geometric point.

NOTE

With respect to the river referencing system described in this standard, a hydro-location feature can correspond to either the referent that specifies a 'known, already referenced location on the linear element' as described in the OGC Abstract Specification Topic 19, Linear referencing [aka ISO 19148] or the reference location whose distance from a referent can be measured along a linear element.

4.27. hydro(-logic) nexus

Conceptual outlet for water contained by a catchment. The hydro nexus concept represents the place where a catchment interacts with another catchment. Every catchment flows to a hydro nexus, conversely every location in a hydrologic system can be thought of as a hydro nexus that drains some catchment. Similar to catchments, hydro nexuses can be realized in several hydrology-specific ways.

If a given hydro nexus does not have a known hydrology-specific realization or is undetermined, it is termed 'nillable' in this standard. For example, a hydro nexus exists in the form of flow to the subsurface or atmosphere but may be undetermined and unrepresented within implementations focused on surface water hydrology and would not be included or referenced.

4.28. hydrologic realization

A hydrologic feature type that reflects a distinct hydrology-specific perspective of the catchment or hydro nexus feature types. Shares identity and catchment-nexus relationships with the catchment or nexus it realizes but has hydrologically determined topological properties that express unique ways of perceiving catchments and hydrologic nexuses. Distinct from representation in that it is a refinement of the holistic catchment, allowing for multiple geometric representations of each hydrologic realization.

4.29. hydrology

Science that deals with the waters above and below the land surfaces of the Earth, their occurrence, circulation and distribution, both in time and space, their biological, chemical and physical

properties, their reaction with their environment, including their relation to living beings. [9]

4.30. hydrometric feature

Feature of a type which denotes a physical structure intended to observe properties of a hydrologic feature.

NOTE

This definition references the definition of a *hydrometric station* at which data on water in rivers, lakes or reservoirs are obtained on physical and chemical properties of water [9]. A hydrometric feature may be a composite station configured by arranging several monitoring components. Used to sample a hydrologic feature, a hydrometric feature may be considered a *sampling feature* as defined in the ISO Observation model. A sampling feature is described in general in ISO 19156: Observation and Measurement, the special monitoring point of hydrologic observation is described in the OGC WaterML 2.0: Part 1- Timeseries standard [4].

4.31. hydrometric network

Aggregate of hydrologically connected monitoring stations situated on and used for hydrologic observation of a feature such as a catchment or hydrographic network. This definition references the definition of a synonymous *hydrological network* consisting of hydrological stations and observing posts situated within a catchment in such a way as to provide the means of studying its hydrological regime [9].

4.32. hydrometry

Science of the measurement and analysis of water including methods, techniques and instrumentation used in hydrology [9].

4.33. indirect position

Position expressing the location of a feature relative to the known location of another feature. Indirect position requires a logical axis, bounded by the feature being placed and the feature being used as a reference, along which the position can be determined. Common examples in hydrology are mileposts along a river referencing the river source and/or mouth, and the placement of monitoring stations referencing already located stations.

4.34. interior catchment

Catchment in which all waters are collected and drainage is endorheic; an interior catchment does not drain to other catchments. This definition is rooted in the *blind drainage* pattern of water collecting in sinks or lakes not connected to streams [9].

4.35. longitudinal section (of a stream)

Vertical section of a stream in longitudinal direction. This definition is rooted in the definition of a *longitudinal section* along a channel at its center line [9], but generalized for all types of vertical section along a line.

4.36. longitudinal section (of a stream bed)

Longitudinal section of a stream bed in a vertical plane. This definition references the definition of a *bed profile* describing the shape of a stream bed in a vertical plane [9].

4.37. main stem (also mainstem)

Main course along which water flows in a catchment excluding tributaries. For any identified catchment, the flowpath connecting inflow and outflow locations would typically correspond to or follow the main stem, but the main stem is conceptually broader than the catchment flowpath concept of HY_Features.

4.38. mapping

Establishing a semantic relationship between concepts in different information models using a formalism that specifies how elements from a source information model may be transformed into elements of a target model. Every pair of N models generally require a separate (2-way) mapping for each source concept (a total of $N!/[2(N-2)!]$ mappings). Mappings that in contrast involve transformation by way of a common concept can be more efficiently expanded to more than two models as each additional model only requires mapping once into the set of common concepts (N mappings).

4.39. named feature

Feature identified by a name. Hydrologic features may have multiple names depending on the cultural, political or historical context.

4.40. nillable

Nillable is meant in this standard to signify that a feature property logically exists but may not be determined in a given implementation.

4.41. referent

Feature with a known location being used as a reference to locate another feature on the logical axis that stretches between the two. The (indirect) position of a new location is expressed as the distance along that linear element from the known referent to the feature being placed.

4.42. representation

Any process-able data, data set, or data product which characterizes a given feature concept.

4.43. river referencing

Referencing along a river applied to place a feature on a (linear) waterbody feature. The feature location is specified as an indirect position expressed as distance along the watercourse on which the feature is to be placed.

NOTE

A (hydrologic) feature of interest which is located along the locating one-dimensional flowpath between inflow and outflow nodes, corresponds to the linear referencing described in the OGC Abstract Specification Topic 19, Linear referencing 'specifying a location relative to a linear element along that element' [ISO 19148].

4.44. storage (of water)

Impounding of water in surface or underground reservoirs, for future use. [\[9\]](#)

NOTE

NOTE: Storage refers to a body of water from the perspective of a usable water resource. The management of a reservoir itself, as a human action with the objective of efficient and sustainable use of the resource, is not in the scope of the conceptual model.

4.45. stream

Water, generally flowing in a natural surface channel, or in an open or closed conduit, a jet of water issuing from an orifice, or a body of flowing groundwater [\[9\]](#).

4.46. waterbody (also water body)

Mass of water distinct from other masses of water [\[9\]](#).

4.47. watercourse

Natural or man-made channel through or along which water may flow [\[9\]](#), including large interstices in the ground, such as cave, cavern or a group of these in karst terrain.

Chapter 5. Conventions

This section provides details and examples for any conventions used in the document. Examples of conventions are symbols, abbreviations, use of XML schema, or special notes regarding how to read the document.

5.1. Identifiers

The normative provisions in this specification are denoted by the URI

<http://www.opengis.net/spec/{standard}/{m.n}>

All requirements and conformance tests that appear in this document are denoted by partial URIs which are relative to this base.

5.2. Symbols (and abbreviated terms)

CHy

WMO Commission for Hydrology

GML

Geography Markup Language

GRDC

Global Runoff Data Centre (GRDC)

GWML2

GroundwaterML 2

HDWG

OGC Hydrology Domain Working Group

ISO

International Organization for Standardization

OGC

Open Geospatial Consortium

OWL

Web Ontology Language

UML

Unified Modeling Language

WaterML 2

working title for the indented suite of water-related OGC standards

WIS

WMO Information System

WIGOS

WMO Integrated Global Observing System

WMO

World Meteorological Organization

XML

eXtensible Markup Language

5.3. UML notation

Most diagrams that appear in this specification are presented using the Unified Modeling Language (UML) static structure diagram, as described in Sub-clause 5.2 of the OGC Web Services Common Implementation Specification (OGC 04-016r2). UML classes are named in UpperCamelCase and property names in lowerCamelCase.

5.4. WMO Terminology

The HY_Features model uses—as far as possible—terminology recommended by the WMO Commission for Hydrology for use in the WMO Member countries. The key reference is the "International Glossary of Hydrology" [\[9\]](#) a joint publication of the WMO and the UNESCO (hereinafter referred to as WMO/UNESCO glossary of hydrology). Wherever appropriate, terms from this glossary are applied to the featureconcepts in this standard to capture meaning and contextualrelationships. The synonym approach widely used in this glossary is interpreted as signifying that synonymous terms are not necessarily synonymous in every respect. Differences in terminology were explored through reconciling the explicit definitions documented in the glossary with usage reflected in various data sets and products. The accepted terms were augmented with the relationships inferred from other terminology in order to define complex terms that do not clearly distinguish between a specific logical concept and its geometric representation or between a general term and its specific conceptual meaning. The definitions used in the conceptual model described in this standard may be understood as a conceptual refining and/or narrowing of the definitions given in the WMO/UNESCO Glossary of Hydrology.

Some words have been avoided because of their disparate uses in various implementation schemes. The words "reach" and "mainstem" are examples that are used to refer to such a variety of collections of features, that they have been avoided. Similarly, the term "watershed" is used and defined differently depending on its context and has been avoided. Unfortunately, it is inevitable that the terminology in HY_Features will conflict with one or more schemes or implementations of hydrologic features. In these cases, great care will need to be taken and the specific feature type names from HY_Features should be used when necessary.

Though rooted in the definitions given in the WMO/UNESCO Glossary of Hydrology, many of the hydrologic features in this standard have been defined more specifically for relevance to the surface water domain. Some requirements defined in this standard refer to the Scoped Name

concept of ISO 19103: Conceptual Schema and any such *Scoped Name* implementations should reflect if possible a name endorsed by the WMO.

5.5. Naming convention

The *HY*-prefix used in the UML model follows the ISO naming conventions for UML elements. There is no explicit requirement to use this same name in a corresponding implemented term but conformance will require that each such term be clearly connected back to its corresponding conceptual model term.

Chapter 6. Clauses not Containing Normative Material

6.1. The abstract idea of the hydrology phenomenon

Processes that continuously deplete and replenish water resources cause or result in a wide range of phenomena that are the subject of monitoring, modeling and reporting in hydrology and related sciences. This standard conceptualizes these distinctly named or otherwise uniquely identified real-world hydrologic phenomena as hydrologic features.

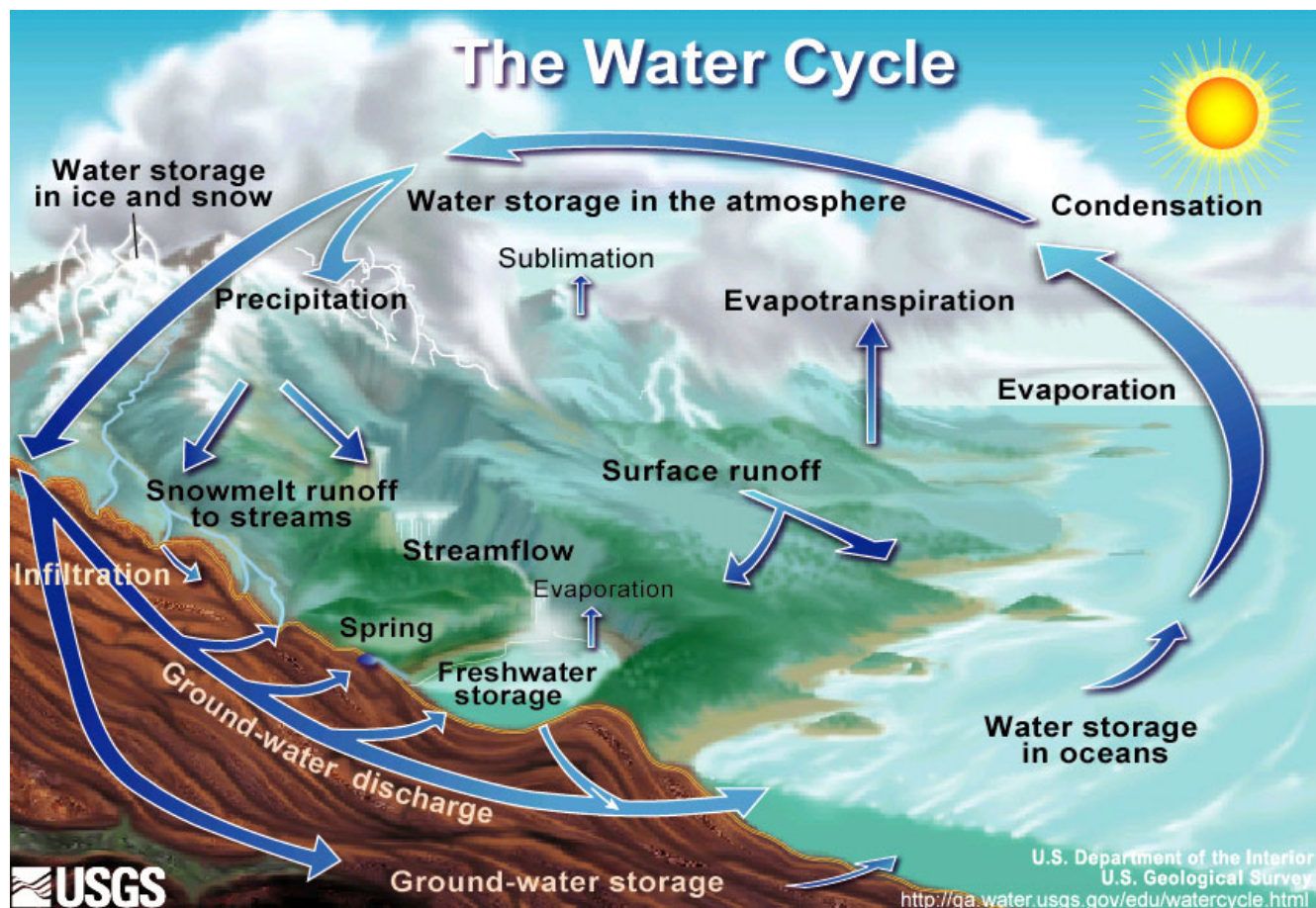


Figure 2. Processes of the Hydrologic Cycle

Water is moving from the atmosphere to the Earth and back to the atmosphere due to the processes forming the Water Cycle (Figure 2). Water from precipitation reaching the land surface is accumulated in waterbodies occupying empty space on the land surface or in water bearing formations of soil and rock. Excess water overflows these formations and is driven downhill by gravity. Water flowing over soil or rock causes erosion to occur. This erosion tends to concentrate flowing water into waterbodies that flow downhill using a connecting system of channels intersecting other waterbodies along their way to a common outlet, conceptualized as a single (potentially complex or ambiguous) hydrologic location which may be described as an outlet, confluence, or nexus.

Looking back upstream from the outlet location, the corresponding catchment feature draining to it can be thought to have several distinct hydrology-specific forms: a flowpath feature, a catchment

area feature, a catchment divide feature, a network feature of waterbodies, a network feature of channels (or waterbody containers), or a network feature of hydrometric (or observation) stations. All these are examples of what are referred to in HY_Features as *realizations* of the holistic catchment concept.

The most general conceptualization of hydrology phenomena is the catchment. A catchment is a recognized unit of study where hydrologic processes form physiographic features that are described in various data products. It serves as the commonly recognized unit of water resources assessment and management that can cross administrative jurisdictions. In multi-stakeholder collaboration and cross-domain research projects, catchments may be recognized as shared monitoring and reporting units. Most typically, river monitoring stations are assigned to a recognized catchment. Catchment inflow and outflows connect information between recognized catchments. Regardless of the way catchments are realized and represented, their basic identification can serve as the critical link between disciplines and jurisdictions. Examples of defined organizational catchments include the "Hydrologic Unit Code" (HUC) catchments defined by the U.S. Geological Survey for research and regulatory data systems to use as a reference [7] and "River Basin Districts" of the European Water Framework Directive [1]. In contrast to these, monitoring and research stations and hydrologic locations like bridges and confluences often imply or hydrologically determine identified catchments.

In this specification, a catchment feature provides a means to have an *identified* grouping of hydrologic study activities and data artifacts. A catchment may be *realized* by catchment-realization features whose connectivity may be described using one or more topological properties and geographic characteristics *represented* by geometric properties. The term *realization* is used here to imply that a holistic feature type like catchment can have more specific hydrologic feature types that share identity with but express a different aspect of it. The term realization is not meant to be interpreted as a Unified Modeling Language realization relationship.

The three terms, *identification*, *realization*, and *representation*, are very important to understanding the HY_Features conceptual model. *Identification* of a hydrologic feature implies that a feature has a hydrologically significant identity and would normally have a name in common usage. *Realization* implies a particular hydrologic feature type which has specific hydrologically determined topological properties and relationships. *Representation* implies that the particular realization of a feature has been defined by a particular geometric shape. For example, the Amazon River is *identified* in that we have a name for it and a vague notion of the Amazon River catchment. We can *realize* the Amazon River catchment, thinking of it in a number of ways: as a boundary ridge line, a surface covering the drained area, a linear flowpath from source to mouth, etc. Each of those hydrologic realizations may have different representations: the boundary may have surface and groundwater contributing variants, the area might have elevation and land cover variants, the flowpath might have a one dimensional simple and three-dimensional complex variant. Using HY_Features, each of these representations could be identified as being a particular representation of a particular hydrologic realization of the Amazon River catchment.

Depending on application and (spatial) scale, the same catchment may be realized in a number of different ways. The following are examples of the multiple realization pattern:

1. The most typical example is that scaling a map-visualization up or down requires realization of a catchment as a single flowpath or boundary at one scale and a network of flowpaths or boundaries at another scale.

2. Analyses and reports from different disciplines may reference differing realizations of the same conceptual catchment. For example, one discipline may realize a network of waterbodies while another realizes a network of channels.
3. Some applications require cartographic (visual) realizations while others are focused on topological (network connectivity) realizations only.
4. A catchment may be realized geometrically by streamline, drainage area/surface, bounding polygon, or stream network, and realized topologically as a face, or an edge.

Figure 3 illustrates some possible alternative catchment realizations.

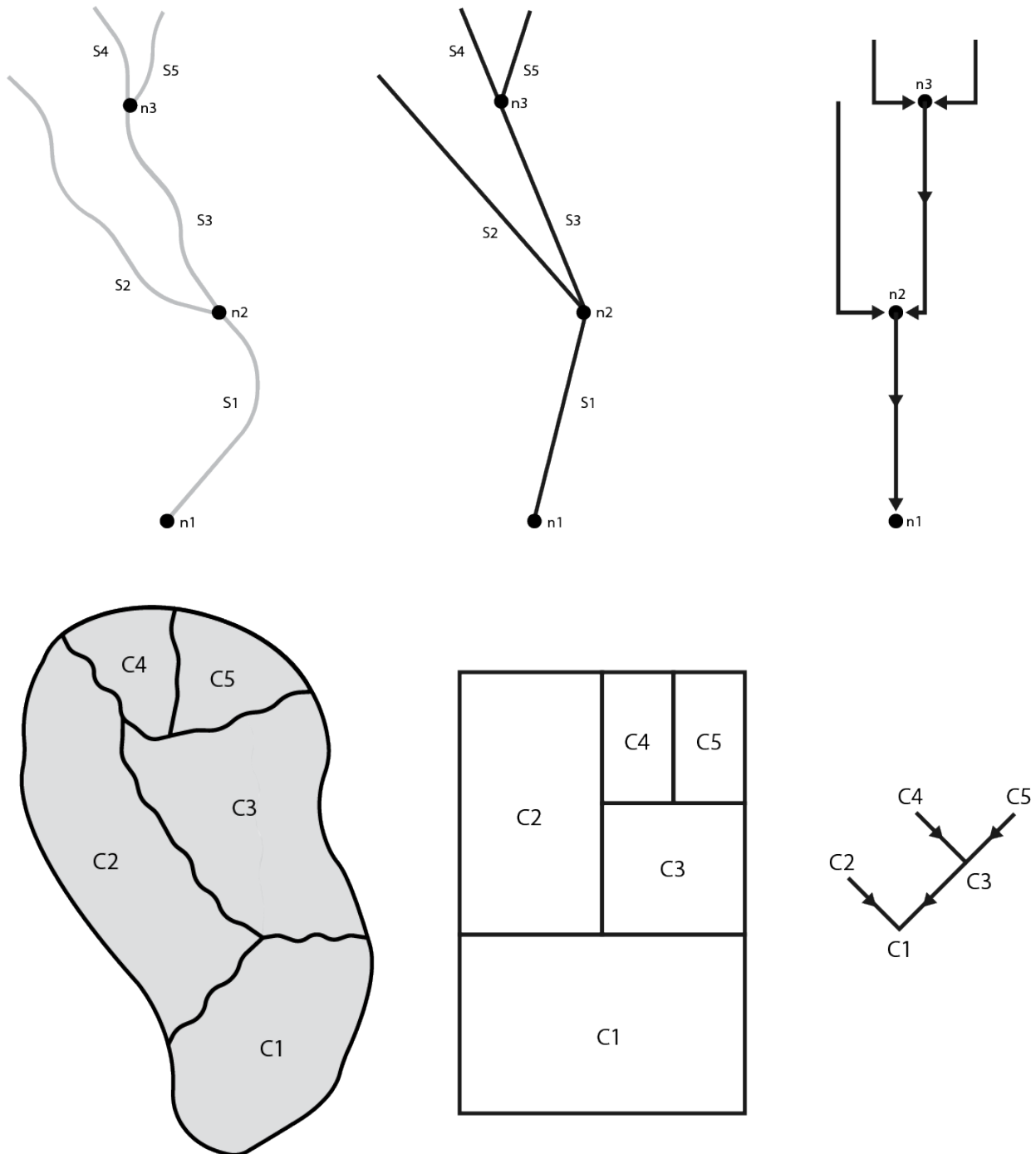


Figure 3. Illustration of multiple representations of a catchment

6.2. Catchment and realizations of the catchment concept

The core concept of the HY_Features model is that studies of hydrology phenomena have a need to reference common conceptual entities of the hydrosphere—such as catchment, waterbody, channel, or monitoring position—through the use of feature types defined in a specific model (as per ISO 19109 General Feature Model). Depending on the field of study or application, complex hydrology phenomena may be hydrologically realized as different feature types. Recognizing the catchment as the holistic unit of study allows multiple realizations and the information they carry to be connected to the same identified conceptual entity. [Figure 4](#) is a graphic meant to represent the basic catchment concept visually without highlighting any particular realizations.



Figure 4. This figure should be interpreted as the idealized catchment concept independent of realization or representation. Later figures use it as a base upon which realizations are highlighted.

Fundamental to the catchment concept is that each catchment is defined by and paired hydrologically with a *hydro nexus* which forms the outlet to which all catchment waters drain and potentially the inlet that corresponds with the outlet(s) of upstream catchment(s). A hydro nexus is always defined as the feature that provides connectivity between catchments and can have a hydrology-specific realization that is a hydrologic location. Hydrologic locations stand alone as

features such as confluences, stream gages, pour points, or bridges and can be the real-world feature that we think of as the location of a nexus between two or more catchments. It's important to highlight that hydrologic locations do not have to realize a hydro nexus. In many cases, they will be network-linked features without associated catchments, while in other cases, they are realizations of hydro nexus features.

Hydro nexuses, like catchments, are features that may have one or more hydrology-specific realizations that are single locations, complex locations, or even diffused or indistinct geographies. In the absence of such realizations, systems of catchments and hydro nexuses can form a topological complex based on their hydrologic connectivity even if their topological elements are not or cannot be represented geometrically. Building on concepts of hydrologically determined catchment topology and multiple catchment realizations, a collection of hydrologic features that realize a larger catchment can be said to form a *hydro complex* that is comprised of the collection of catchment and hydro nexus features and any other feature(s) that realize the catchment and/or the hydro nexus. A hydro complex may include multiple realized topologies such as flowpath, catchment area, stream or channel networks.

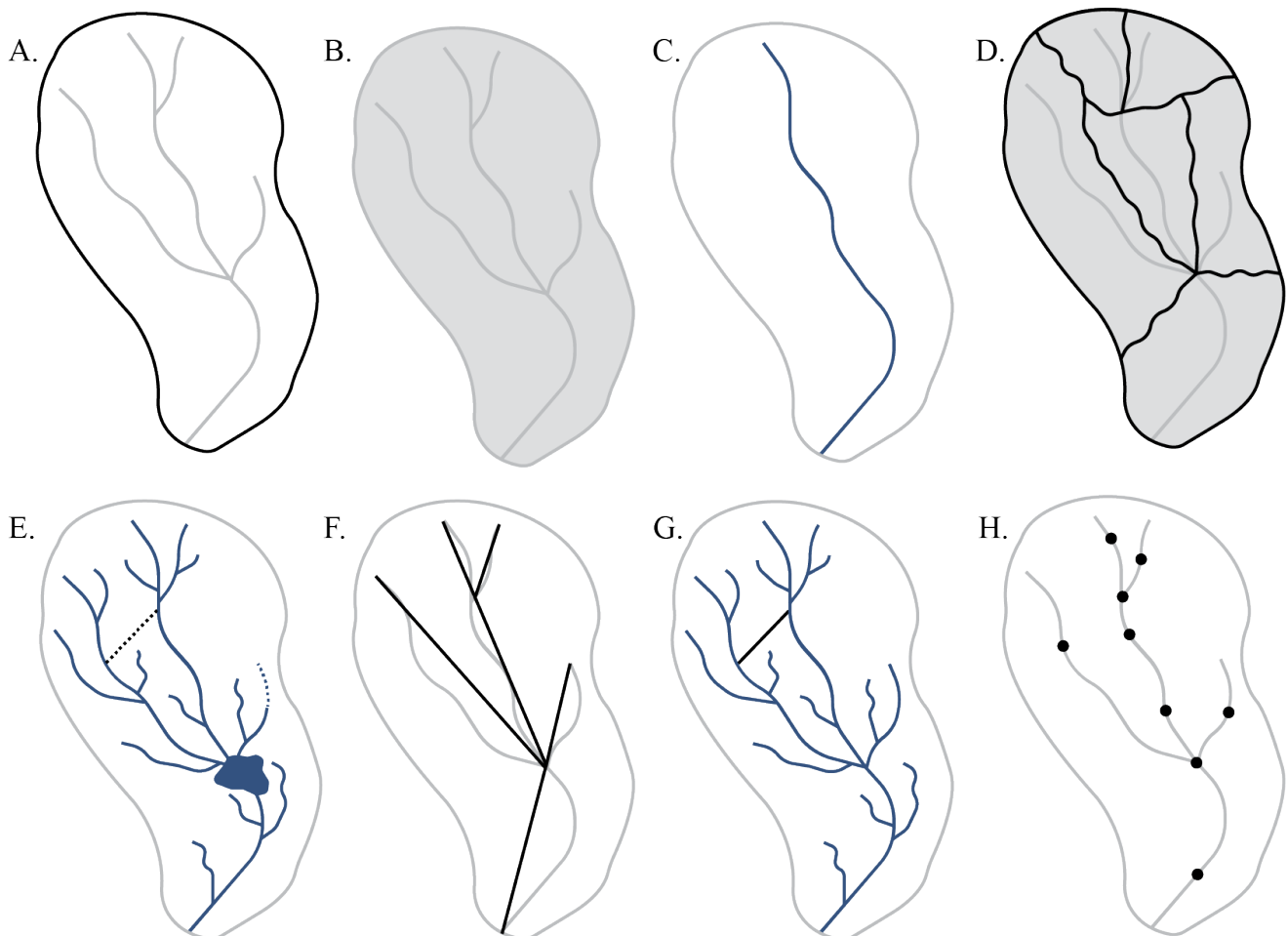


Figure 5. Multiple catchment realizations (top left to bottom right): a) catchment boundary, b) catchment area, c) catchment flowpath d) subcatchment network, e) hydrographic network, f) geo-schematic network, g) flow network, h) hydrometric network of monitoring stations.

Catchment area, catchment divide, and linear flowpath are the most common topological realizations of the catchment concept, and are widely used to create cartographic representations of a catchment. Map layers that provide visualizations of the hydrographic network of waterbodies (typically as blue lines for small rivers and blue polygons for larger rivers and lakes) or of channels

(typically lines displaying a drainage pattern indicating the path that flow may follow), or a network of hydrometric monitoring stations, are usually combined to represent the catchment as a whole. [Figure 5](#) adds graphical representations of such realizations to the idealized catchment of [Figure 4](#).

6.2.1. Hydrologic Features Schemes

Each hydrology-specific realization of a catchment is a different way of thinking of the catchment that emphasizes different hydrologic and/or topological characteristics. While these distinctions are useful, many nuances of a given dataset may not be evident from the feature types alone. For example, a map of catchment polygons may portray a non-overlapping coverage of sub-catchments, or a collection of overlapping catchment polygons that correspond to monitoring stations. It is very important to understand that every hydrologic feature dataset follows a unique "scheme" with regard to the general concepts of HY_Features. That is, catchments' type and role in a particular application or dataset, such as catchment hierarchy, upstream-downstream relationships, and cross-scale realization correspondence, will vary according to the needs of the application.

Some applications have no need for geometric representations of catchments at all. In such schemes, topological networks of catchments without geometries are used by themselves. An example of this might be a data system supporting hydrologic modeling. Geospatial data may be used to parameterize models that then run only using topological catchment relationships. In this kind of scheme, the topological realization may not correspond to a single geometric representation. For example, when it is modeling a diffused area of drainage between two model units, a hydro nexus may take on the topological role of a node without being represented geometrically as a single point.

A very common scheme that includes geometric representation is sometimes referred to as the "reach-catchment" scheme and is typified by the U.S. NHDPlus [\[10\]](#). In this case, the catchment network forms a continuous coverage of incremental drainage units where each catchment corresponds to one and only one flowpath. This scheme comes about as a result of elevation derived hydrography where, at a given scale, incremental drainage polygons are defined for every confluence-to-confluence flowpath. This scheme can be described using HY_Features, but many of its specific constraints and nuances are implementation details that would be specified in a profile and/or implementation of HY_Features.

Considering datasets that include multiple realizations and/or representations of features across two or more scales, the idea of the implementation scheme is very important. For example, consider a dataset that has high-resolution and low-resolution variants of reach-catchments, as described above. The flowpaths of the low-resolution catchments may or may not be represented by the union of the set of high-resolution catchments' flowpaths that connect its inflow to outflow. A scheme may also include different kinds of realizations or representations for higher or lower resolution features. For example, at one scale, all waterbodies in a network may be represented as linear flowpaths merely connecting catchment inlet to catchment outlet. At finer scales, the same waterbodies may be represented as waterbody polygons that show inundated area or even as some form of mesh or surface representing the containing bathymetry and/or the waterbody volume. All these examples are supported by HY_Features, but would need to be specified as a profile or with implementation by a particular application.

Another example of a dataset-scheme is the idea of a "contracted catchment" and a "contracted

node" which are used in the Australian Hydrological Geospatial Fabric [11] to describe catchments, and associated outlet locations. The word contracted is used as in a legal contract, meaning that a "contracted node" is one for which a contract that it will be realized and given a representation in future versions of the dataset has been established. Many hydrologic data sets have similar varying levels of permanence and governance of features' identity. As far as HY_Features is concerned, these are implementation details that would be specified as a profile or implementation of the model.

Specific feature types defined in the HY_Features model include HY_HydroFeature (in section 7.3.1), HY_Catchment, HY_HydroNexus, HY_CatchmentRealization, HY_HydroLocation, HY_CatchmentArea, HY_CatchmentDivide, HY_Flowpath, HY_HydroNetwork and HY_CartographicRealization (section 7.3.2).

6.3. Catchment topology and hierarchy

An unlimited number of overlapping catchments can potentially be defined in a given region since every point in that region corresponds to some catchment that drains to it. However, catchments are normally connected in drainage networks and built around significant features of the terrain such as confluences. Catchment networks, that might form a continuous coverage of the landscape, provide continuity between catchments, the ability to aggregate catchments, and to trace flow up- or down-stream.

In a network of catchments, morphological detail may be specified in many ways. Inflows and outflows are often complex where water flows out of one catchment and into another. As shown in [Figure 6](#), catchments may connect through simple confluences (Figure 6a), waterbodies or wetlands (Figure 6c), intermittent or subsurface flows (Figure 6d), complex braided streams (Figure 6e), or distributary systems like deltas (Figure 6f). In some situations, diffuse (multiple) inflows can be conceptually joined in a 'conjoint' catchment (Figure 6b) and spread (multiple) outflows may be joined in a catchment flowing out at a single, conceptual outflow (Figure 6e).

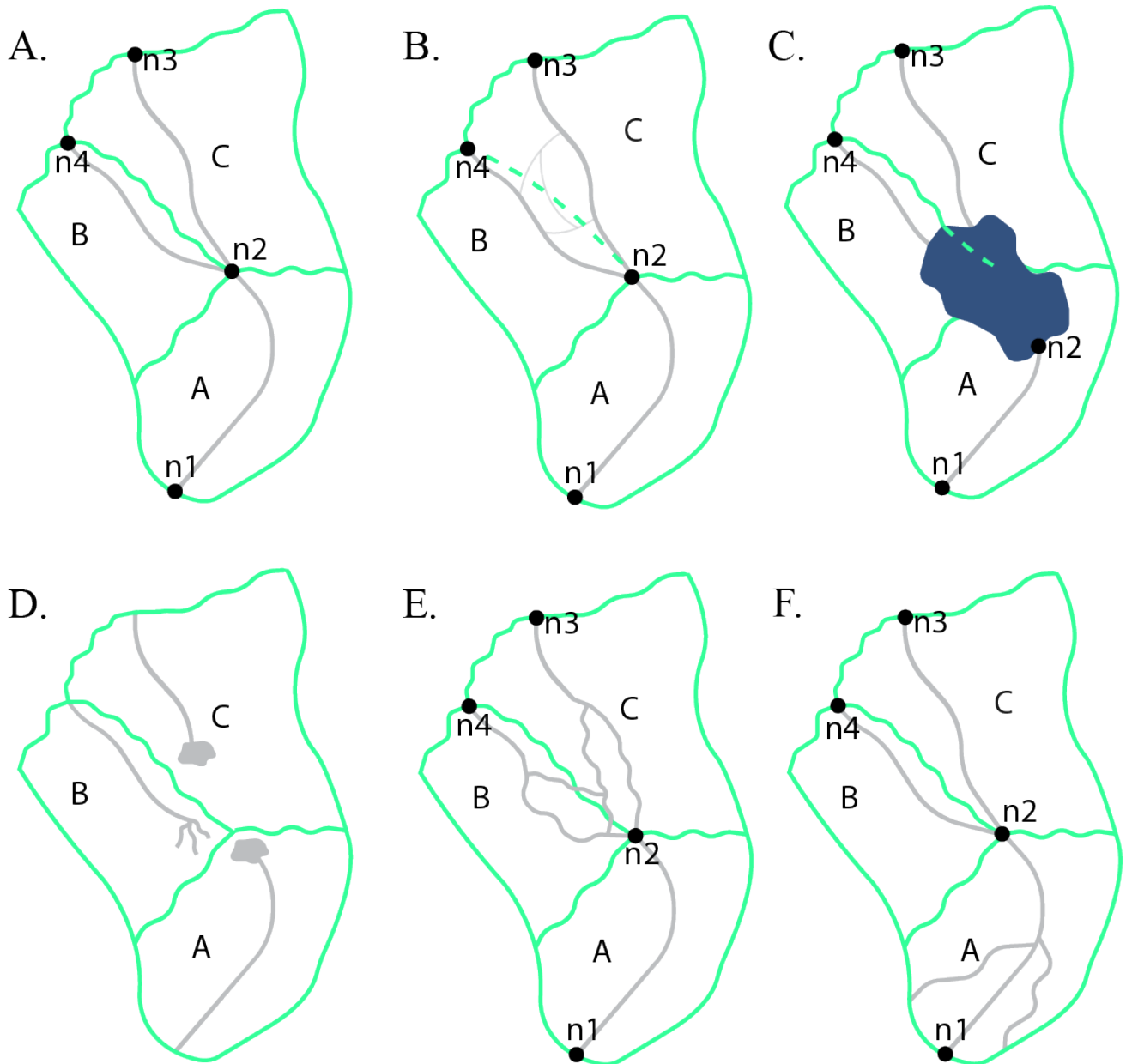


Figure 6. Catchment connectivity examples (top left to bottom right): a) Simple catchments with one inflow and one outflow each; b) conjoint catchments with an ambiguous divide flowing into a single downstream catchment; c) catchments joining in a waterbody or wetland with no clear network at their shared nexus; d) catchments joining through intermittent or subsurface flows; e) catchments that join through areas of complex or braided channels with an ambiguous divide near their junction; f) catchments with distributary hydro nexuses such as in a delta.

Although these cases require different geographic representations, they can be represented using the same pattern of the catchment and hydro nexus. Since all these cases can be specified referencing a simple internal edge-node catchment topology, no special treatment is required to handle the variation of flow processes. While [Figure 6](#) illustrates a simple dendritic junction, and a method to handle complexity through encapsulation, it's important to note that HY_Features can support non-dendritic network topology where a given hydro nexus may be distributary and contribute flow (be an inflow hydro nexus) to multiple catchments.

Any catchment may also be nested in a larger containing catchment or split into multiple sub units to define catchment hierarchies. Two types of catchment hierarchical relations are supported in HY_Features: basic nesting and dendritic aggregation. Basic nesting allows any catchment to

reference a containing catchment (Figure 7) without defining any particular interconnections between the two. Dendritic aggregations (Figure 8) consist of specialized dendritic catchments that contribute exorheic flow to an outlet and support simple topological relationships that allow determination of flow from upstream to downstream catchments. Specialized interior catchments add support for endorheic flow or interior drainage within dendritic aggregations.

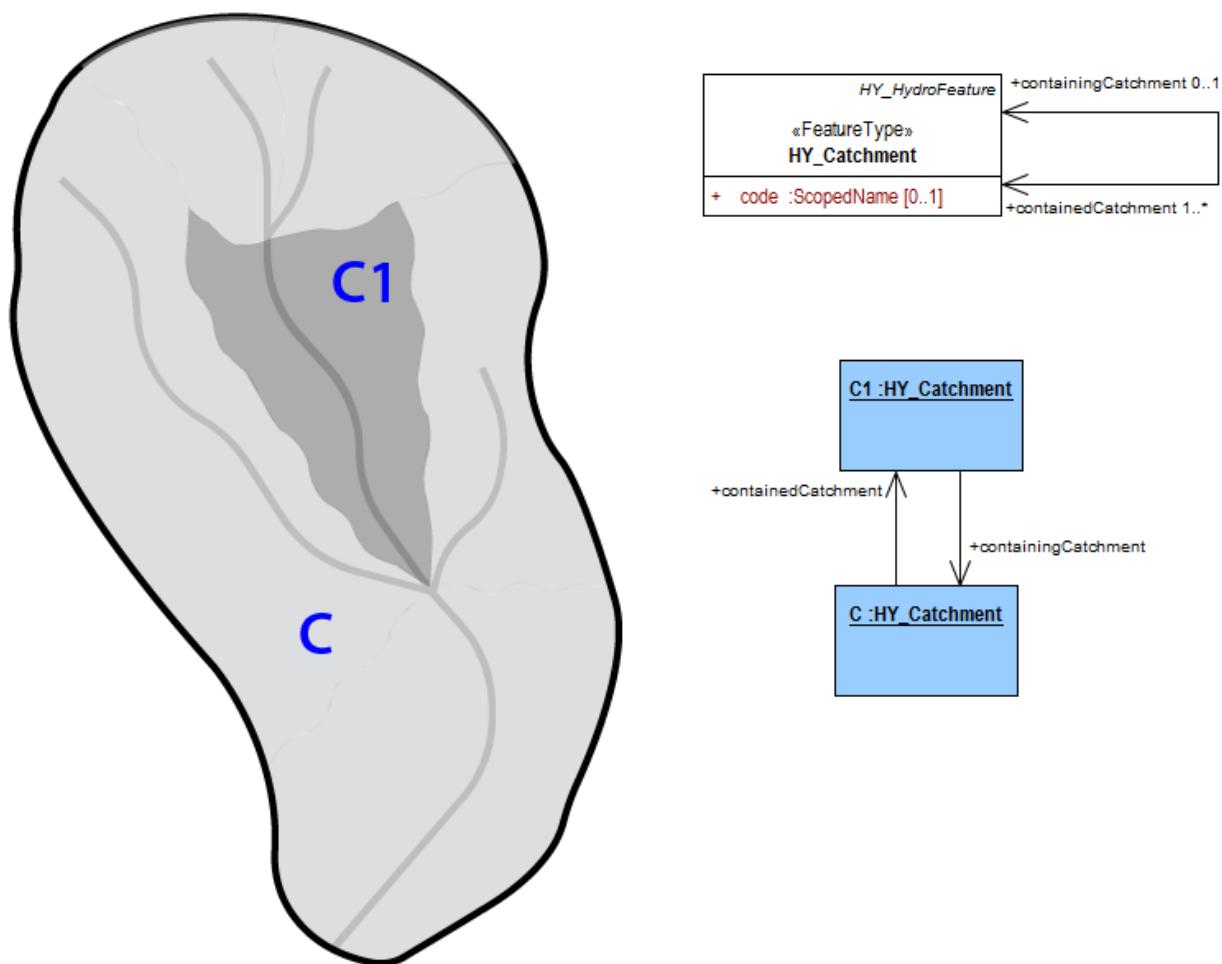


Figure 7. Catchment hierarchy, with one catchment (dark grey C1) nested within another catchment (light grey C) and corresponding HY_Features UML classes.

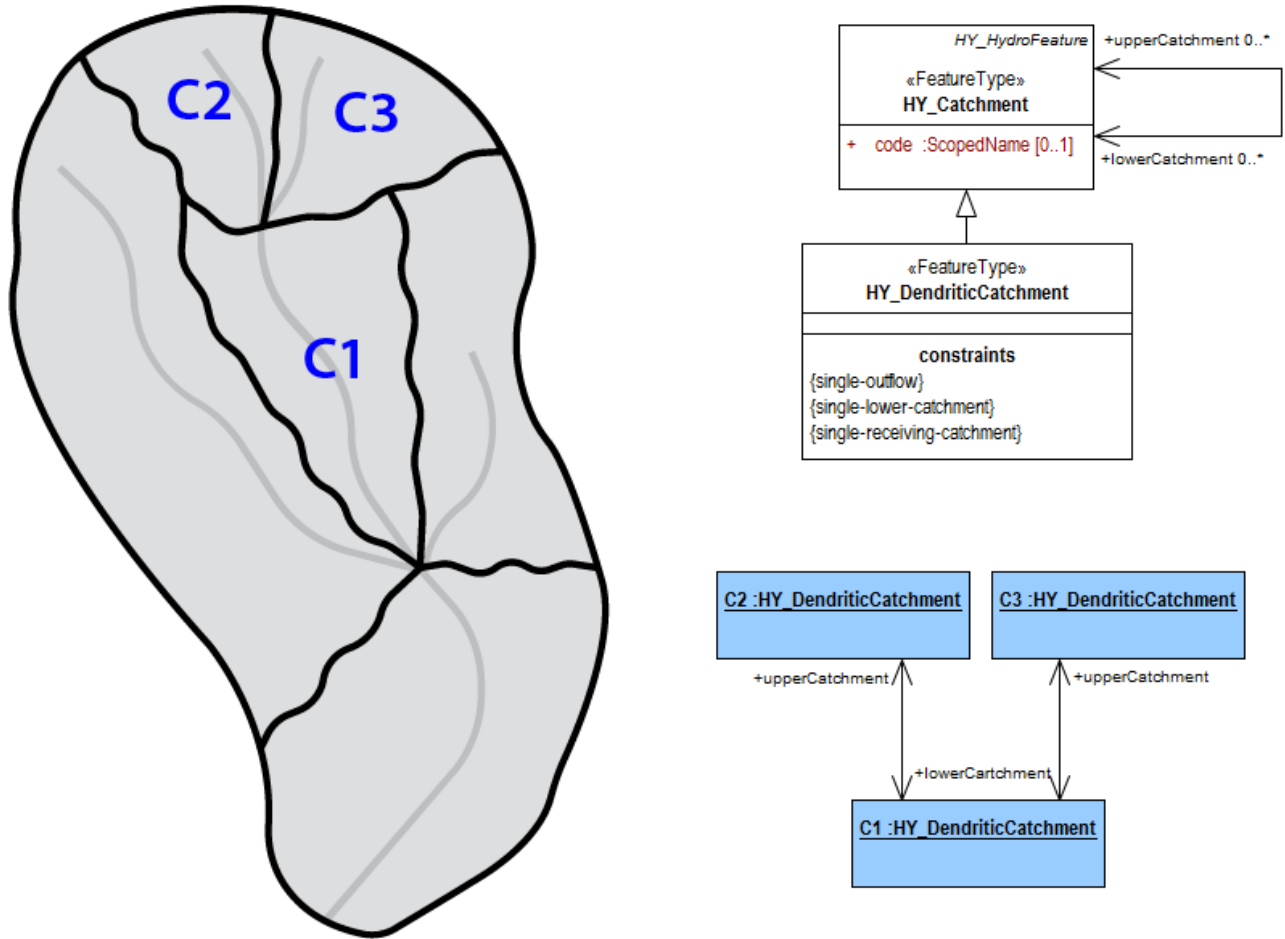


Figure 8. Catchment hierarchy with smaller catchments (C1, C2, C3) part of a dendritic catchment network, which is itself a catchment and corresponding HY_Features UML classes.

6.4. Catchment network realization

As discussed above, catchments may have a number of hydrology-specific realizations. A network of catchments that interact at hydro nexuses can be realized as a network of catchment realizations. For example, a network of catchments, each realized as a flowpath, can be realized as the network of linear flowpath edges connected by hydro location nodes. Figure 9, Figure 10, and Figure 11 illustrate how a single catchment C1 is realized as a catchment area (light grey catchment area A) and also as a flowpath (red line F). Each catchment is potentially connected to other catchments at its outflow nexus n1 (Figure 10) and/or inflow nexus n2 (Figure 11). The flowpath geometry may trace the main flowpath through the catchment or it could be a purely schematic straight-line representation of a topological edge. Figure 9, Figure 10, and Figure 11, include UML diagrams that describe the hydrologic features highlighted in the figures.

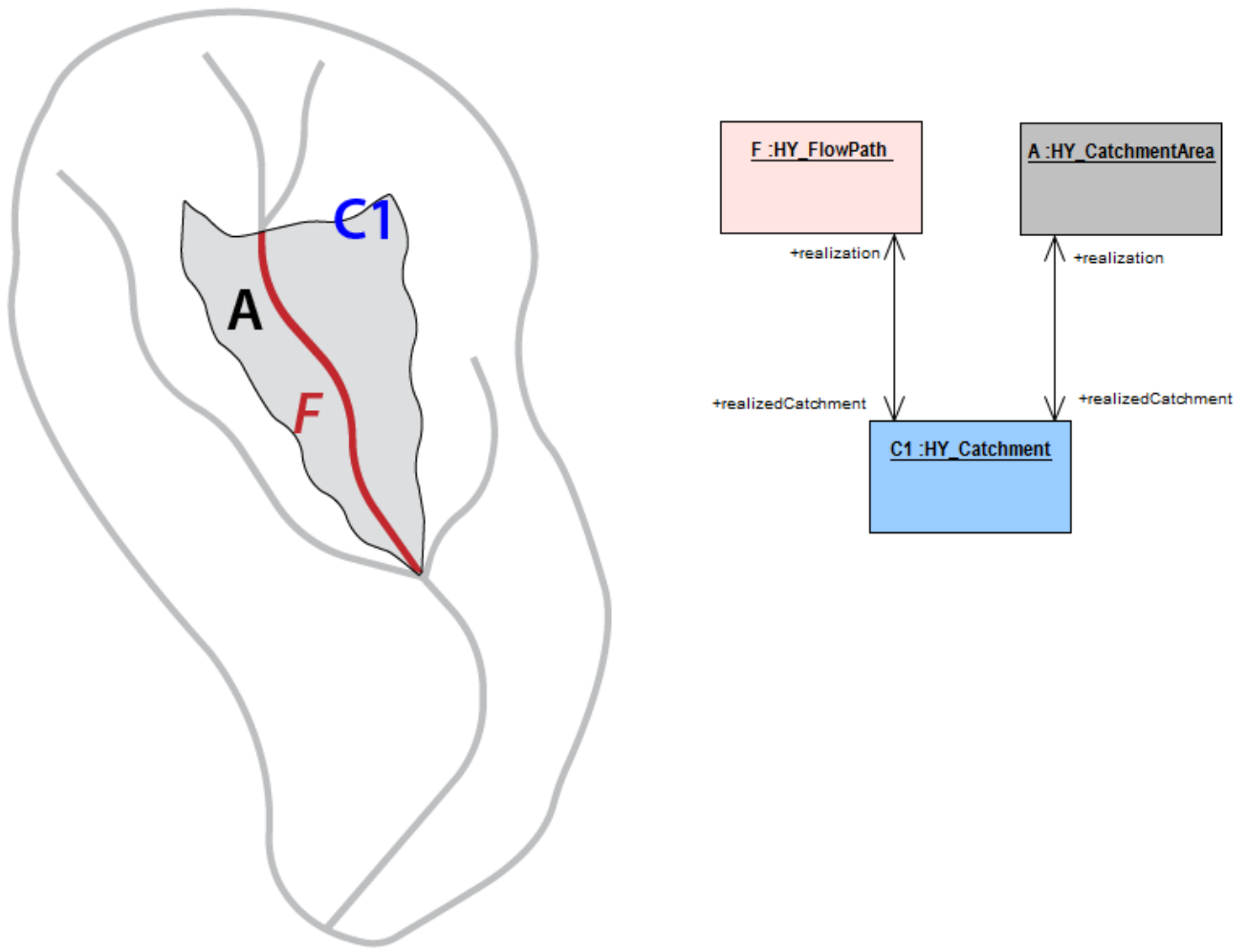


Figure 9. Catchment area (grey area A) and flowpath realization (red line F) that connects catchment inflow to outflow for a defined hydrologically significant unit (C1) and corresponding HY_Features UML classes.

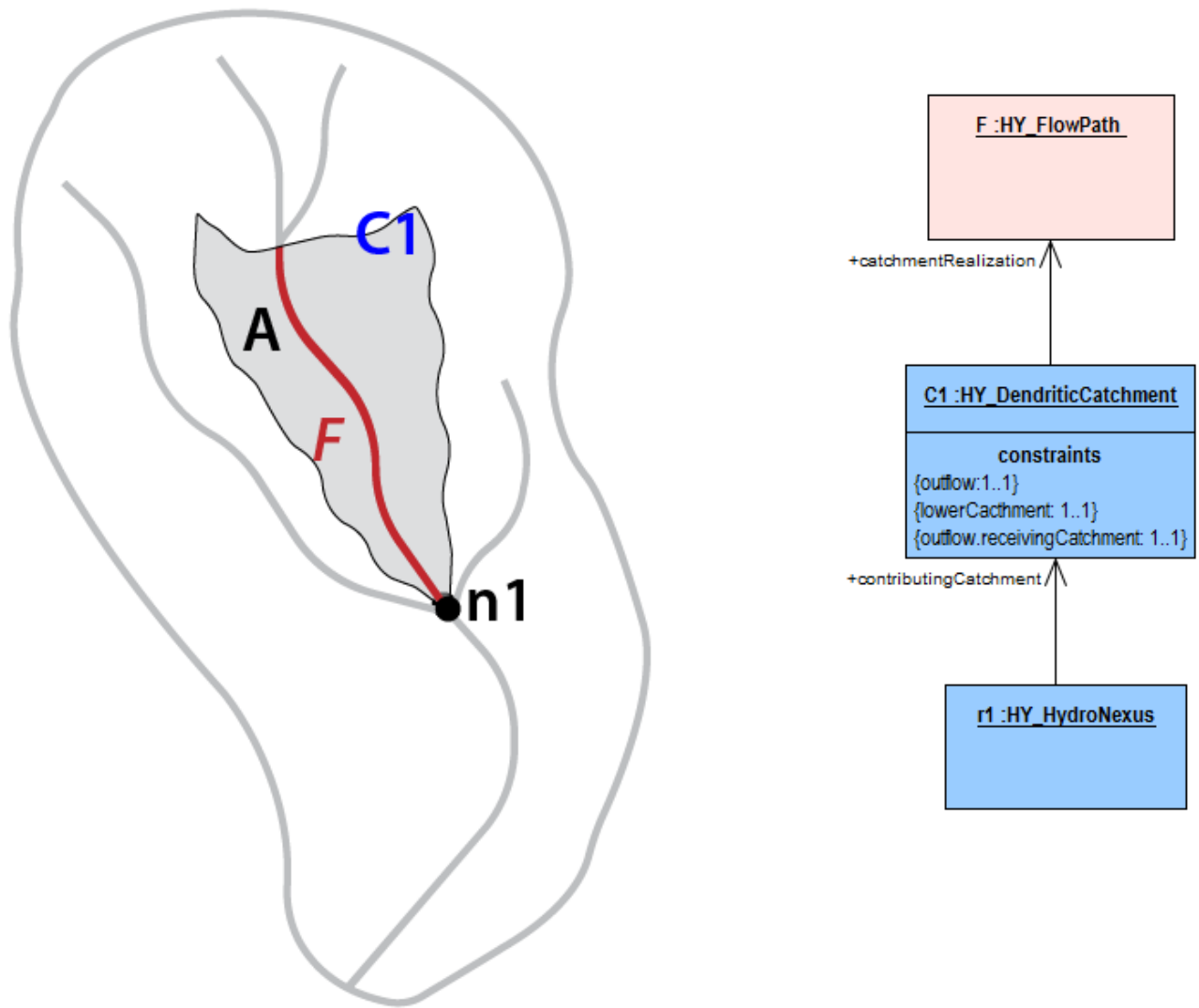


Figure 10. Catchment (C1), realized by a flowpath (red line F) and area (grey area A), contributes to a common outflow hydro nexus node (n1) and corresponding HY_Features UML classes.

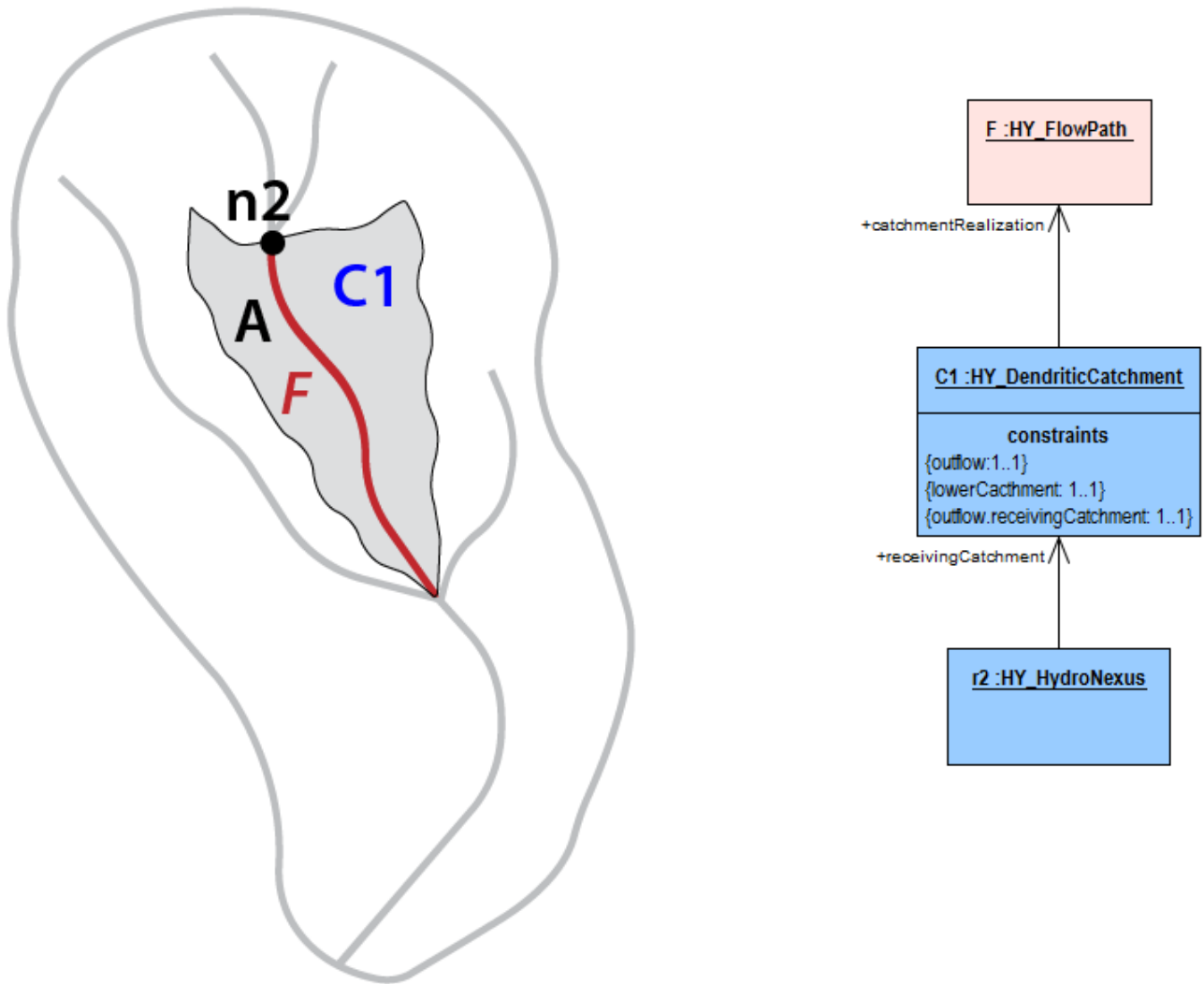


Figure 11. Catchment (C1), realized by a flowpath (red line F) and area (grey area A), receives inflow from hydro nexus node n2 and corresponding HY_Features UML classes.

In a network of dendritic catchments, one or more catchments may contribute outflow to a given hydro nexus, but only one catchment can receive inflow from that nexus. This hydrology-specific topological relationship is maintained regardless of the geometric representation of the hydro location which realizes the nexus. The association role names *inflow* and *outflow* are used to unambiguously describe the flow direction at a hydro nexus with respect to a dendritic catchment.

Catchment networks that appear non-dendritic, such as broad river bottoms with complex braided channels and two or more primary inflows, can be modeled with HY_Features. While a catchment contributes flow to a single outflow hydro nexus, there is no restriction on the number of catchments contributing to a hydro nexus. Figure 12a illustrates a case where hydro nexus nodes n2 and n3, both have two contributing catchments and have one and two receiving catchments respectively. Such situations are quite common in hydrologic systems. Examples include prairie pothole or ponded wetland landscapes, networked urban drainage systems, waterbodies with multiple outflows, and non-surface-contributing regions with ambiguous or complex outflows. While HY_Features does not attempt to model all these types of features, it does support non-dendritic catchments, if an application supports them, and it provides mechanisms to encapsulate such real-world complexity.

By introducing conjoint catchments that encapsulate non-dendritic parts, such complex situations can also be modeled as dendritic networks of catchments. Figure 12 shows a non-dendritic stream network, where it is not possible to determine to what extent flow from catchment F contributes to catchments E or C (Figure 12a) without additional information. Joining the catchments E, B, and C (Figure 12b) and collapsing their inflow (/outflow) nexuses n_2 and n_3 into a single virtual inflow hydro nexus, accumulates all the flow from catchments D and F in the resulting catchment X. Some implementations could go even further, eliminating node n_2 and lumping catchment D into X as well. While not required, this encapsulation approach can be used to model a complex catchment topology as a simple dendritic network.

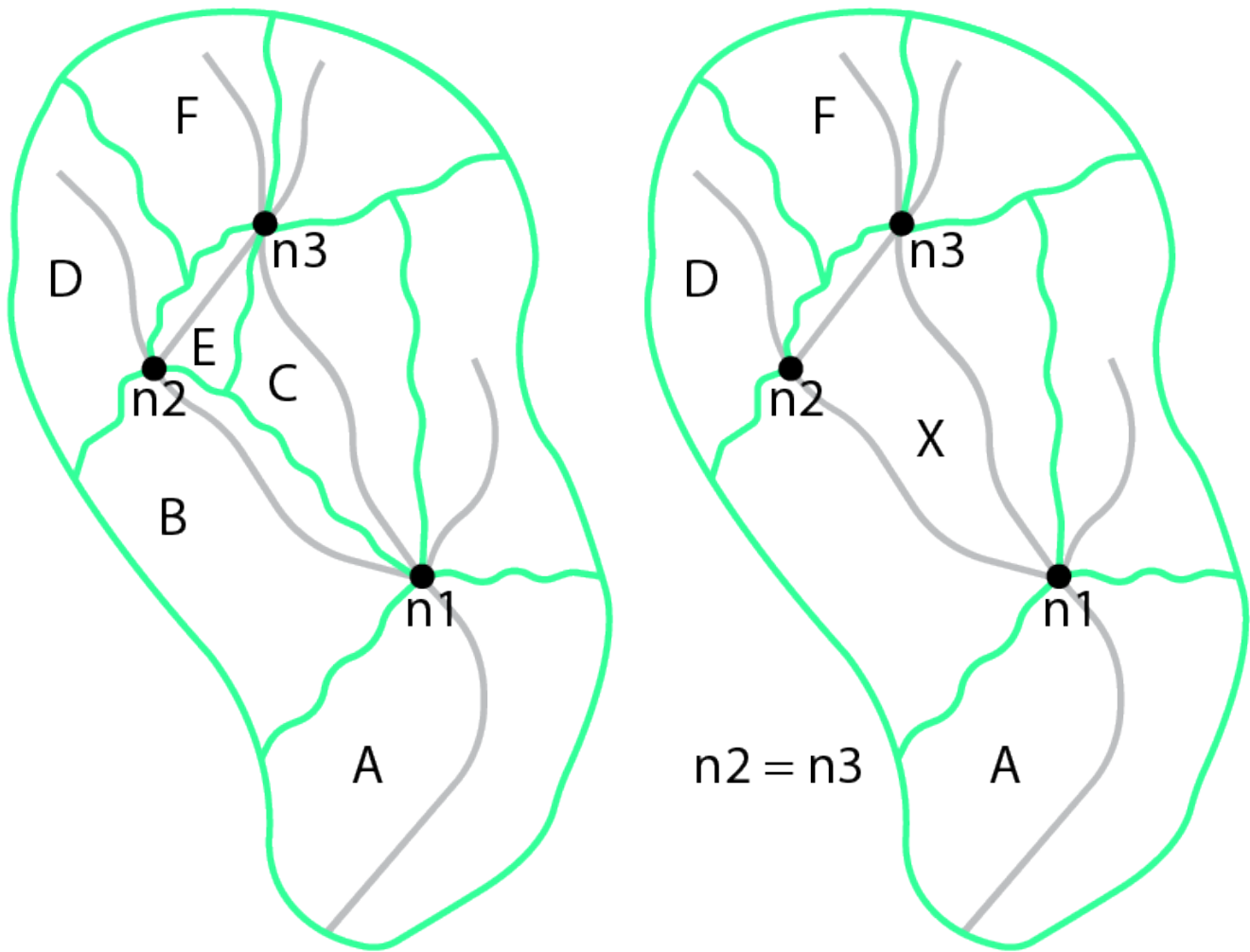


Figure 12. Non-dendritic stream network complexity: a) non-dendritic detailed flow b) unambiguous aggregated flow.

The topological pattern of a catchment network is shared with all of its hydrology-specific realizations, although the topological "level" (solid, face, edge, node) of a realization may vary. A given scheme topologically realizes catchments as a solid bounded by inflow/outflow faces, a face bounded by inflow/outflow edges, or an edge bounded by inflow/outflow nodes. A single catchment may also be realized as a topological complex consisting of all of the flowpath edges, and hydro location nodes forming the surface drainage of that catchment. The topological role that each hydrology-specific realization feature plays may or may not correspond directly to its geometric representation. For example, a waterbody plays the role of a flowpath edge between its inlet and outlet, but may be represented geometrically as a polygon ring.

6.5. Surface water networks

Maps displaying a representation of a catchment are very common in hydrology research and engineering. Depending on the scientific concern and application, as well as the spatial scale of interest, different aspects and details of hydrology phenomena may be represented using application-specific map symbols. HY_Features accommodates this diversity with multiple alternate hydrology-specific realizations of the catchment and hydro nexus concepts which in turn may be represented alternately as geometric points, lines, polygons, or surfaces, or as aggregates of these geometric types. This standard is based on a hydrologically determined topology model of directed hydro nexuses acting as inflow or outflow locations for catchments which in turn connect them. This topological catchment network pattern can be realized in context-specific networks of features which each realizes a single catchment or hydro nexus, especially in hydrographic networks of waterbodies or networks of surface depressions and channels that may contain waterbodies. These network features may in turn have a variety of scale- and application-specific geometric representations. For example, a fixed landmark point on a waterbody, or a cross-section line separating a watercourse can each represent a hydro location node that realizes a nexus within the hydrology-specific topological *hydro complex*.

6.5.1. Hydrographic and channel network

Surface water flows in networks, and so hydrographic data is commonly organized into those same networks. Surface water networks are also self-similar; the patterns of rivers and deltas visible at a continental scale resolve continuously into similar but more detailed nested networks of streams, lakes, confluences, and other features as the spatial scale of mapping and inquiry increases. The HY_Features model of catchment networks and nested waterbody and channel network realizations is intended to address the multi-scale nature of hydrologic data and connect hydrologic phenomena and observations across a range of these scales.

The basic elements of surface water networks at any scale are *waterbodies* and the *channels and depressions* through which they flow and in which they are contained. Following the definitions in the WMO/UNESCO "International Glossary of Hydrology" [9] a waterbody is understood as the mass of liquid water accumulated on or below the land surface as a body of flowing water, which in some parts may have stagnant water that is not moving or flowing. The waterbody concept formalized in this specification is consistent with this definition, but focuses on surface-waterbodies only. A conceptual model capturing the specifics of bodies of groundwater as well as aquifers containing groundwater are provided by the WaterML2: Part 4 - GroundwaterML2 specification [6]. A future WaterML2 specification part is expected to complete the sub-atmospheric hydrologic cycle by addressing features such as recharge zones and springs that connect groundwater with surface water phenomena.

The container for a waterbody, a channel or depression, is commonly understood as a type of natural or man-made watercourse through or along which water may or may not flow [9]. A network of channels (or drainage pattern) exists independent of whether it contains water at a particular time. The HY_Features conceptual model accommodates both targets (waterbody and container) of hydrologic study by defining separately and then linking together waterbody features and containing land surface features. **Note that flow-through or standing lakes and similar features are considered to be types of waterbodies whose container is a depression.**

Connected waterbodies with their associated containing channel network make up the hydrographic and channel networks that hydrology-specific realize the catchment that the networks drain. Individual waterbodies themselves can also be characterized in more detail along vertical cross- or longitudinal sections as well as within horizontal strata as to their distinct thermal, salinity, oxygen, and nutrient characteristics, etc. Such bathymetric and strata information may also be represented as or derived from a surface such as would be derived from Lidar. Waterbodies or their strata may also be recognized as storage reservoir features with water use, regulation, or control characteristics.

In order to form hydrographic or channel networks, waterbodies or channels that hydrologically realize catchments as topological edges need to be connected by way of topological nodes. The HY_Features model therefore connects waterbodies or channels through a hydro location which realizes the hydro nexus corresponding to these catchments. Although an entire network realizes the catchment that it drains to a single hydro nexus, each hydro location node connecting waterbodies or channels can also be thought of as a realization of a hydro nexus that drains the sub-catchment which feeds that waterbody. The catchment relationships defined in the catchment model described in this standard can be used for both the larger catchment realized by the whole hydrographic network and the catchment(s) whose hydro nexuses can be used to connect waterbodies at hydro locations within the hydrographic network. While there is conceptually a hydro nexus realization at the outlet of every flowing waterbody, it's important to point out that not all waterbodies will have identified or realized hydro nexus features in every dataset. However, the conceptual existence of a hydro nexus and a hydro location which realizes it at the outlet of a waterbody is important to form cross-scale and cross-dataset hydro location ties between channels, waterbodies, and the catchments they drain.

It is common practice to realize a catchment as a single main-stem flowpath ([Figure 5c](#)) as well as a complete hydrographic or channel network. There is some choice in which catchments to delineate and realize in this way. As discussed in section 6.2.1, some elevation-derived hydrographic datasets define one associated drainage "reach-catchment" for each stream segment connecting two confluences. Others identify main-stem rivers that flow from their headwaters to a common outlet. In either case, the corresponding catchment typically carries the identity (name or some ID) of the main river and its outlet is considered the mouth of the river. The main stem flowpath serves as both a component of the stream network realizing a catchment and as a standalone realization linking the inflow and outflow of that catchment. Networks of flowpaths and hydro locations can in turn realize larger catchment networks. At small scales, complex networks of watercourses can have one main-stem flowpath made up of many smaller scale reaches. At large scales, a network made up of one reach may serve as the single main flowpath.

Specific HY_Features classes supporting surface water networks include: HY_ChannelNetwork, HY_Channel, HY_Depression (in section 7.4.1), HY_HydrographicNetwork, HY_WaterBody, HY_WaterBodyStratum, HY_CrossSection, HY_LongitudinalSection, HY_Water_LiquidPhase, and HY_Water_SolidPhase (in section 7.4.2).

6.5.2. Hydrometric network

Water bodies are observed using monitoring stations which are typically physical locations with a well-established cross section they monitor. It is common practice to locate a monitoring station in relation to local landmarks and permanent reference points along a stream or in relation to the

outlet of the monitored waterbody. The river reference system, described in section 7.3.3, gives a mechanism to locate such points along a flowpath in relation to located hydro nexuses. When aggregated into a network, monitoring stations within a catchment can be said to make up a logically connected hydrometric network which monitors a catchment.

For the purpose of linking identified monitoring stations, (thought to be the sampling feature in terms of the observations and measurements standard) and a river or other hydrologic feature (thought to be the domain or sampled feature in terms of observations and measurements) a specific hydrometric feature participating in a hydrometric network is defined. The monitoring feature role of hydrometric features is unique in contrast to all other hydro location types in HY_Features, which would be used as observed domain features in observations and measurements.

Specific HY_Features classes supporting hydrometric networks include: HY_HydrometricNetwork and HY_HydrometricFeature described in section 7.5 of this standard.

6.6. Referencing hydrologic locations along a river

It is common practice in hydrology to reference hydrologic locations (typically observation stations, but also designated reaches, or flood plain zones) to an existing dataset, expressing the locations as a distance along a particular linear flowpath waterbody. Given that the flowpath has an established hydro nexus realization, whether located as a network feature or inferred through a dataset convention such as digitization direction, any hydrologic location can be referenced to the network through association with an existing outflow (or inflow) location and distance along the flowpath. Such a network location is often determined on the fly through topological and/or geometric means when a search is executed or as part of some automated data processing routine. This standard does not preclude such techniques, but does not attempt to address the permanence or method of establishing such network locations. Instead, HY_Features provides a linear referencing data model to facilitate relating hydrologic locations across datasets and scales.

To allow expression of cross-dataset links, this standard specifies a system for referencing "along a river" by defining the one-dimensional flowpath which realizes a particular catchment as a linear element and a hydro location which realizes the hydro nexus of that catchment as the reference location. A hydrologic location can be thought of as a tie point between different hydrologic datasets. That is, the hydro nexuses in one dataset can be realized as hydro locations and referenced in another dataset. Similarly, hydro locations may actually be monitoring locations, without identified hydro nexuses - which they theoretically may realize. Whether used to link hydro nexuses and associated catchments or other types of information, an identified hydro location provides a way to link specific network locations between data sources.

The HY_Features conceptual model defines an indirect position which has three properties: 1) a hydro nexus realized by a hydrologically significant "reference location"; 2) a "linear element" defined by the flowpath which starts or ends at the reference location; and 3) a "distance from referent" measure providing an absolute or relative (percentage) value. The relationship between the identified hydro nexus (hydro location) and catchment (flowpath) is either inlet and downstream catchment or outlet and upstream catchment, and can be used to provide upstream or downstream directionality of the distance.

With a specified inflow or outflow hydro nexus as reference location and a specific realization of its

flowpath, each catchment can support its own river referencing. Realized as a hydro location, a located hydro nexus is the potential reference location at the end of a flowpath that could split the original reference flowpath at the newly located hydro location. For example, if two bridges are thought of as the inflow and outflow locations of a catchment, the downstream bridge hydro location, which realizes an outflow hydro nexus, may form the reference location for stream gages upstream from the bridge and the next upstream bridge. Similarly, the upstream bridge hydro location, which realizes the inflow hydro nexus, may be the reference location for stream gages downstream from the bridge and the next downstream bridge.

Note that in these cases, the upstream or downstream orientation of the measurement is always declared in relation to the catchment inflow or outflow. Since this varies in application, the orientation is specified with an inflow or outflow association between the flowpath linear element (catchment realization) and the reference point hydro location (hydro nexus).

Applying the indirect position model, a feature of interest can be related to a hydro nexus and the associated catchment by linking it to an existing hydro location, or as a new hydro location linked to a flowpath linear element and hydro nexus referent. It's worth mentioning that a special case of hydro location that is coincident with a hydro nexus referent (at distance '0') could be considered a realization of the hydro nexus.

6.6.1. Indirect position

Provided that the network of catchments is realized as one-dimensional flowpaths and inflow and outflow hydro nexus locations (i.e. the upstream or downstream end of the flowpaths is known), a feature of interest can be located in the network along the linear flowpath catchment realization. A new location can be placed along a flowpath in reference to an already established inflow or outflow hydro nexus that bounds the flowpath. The new network location can be expressed as a distance along the flowpath 'measured' from the known flowpath end. [Figure 13](#) shows the simplest case, where the inflow of a catchment is some linear distance upstream of a located outflow measured along a flowpath.

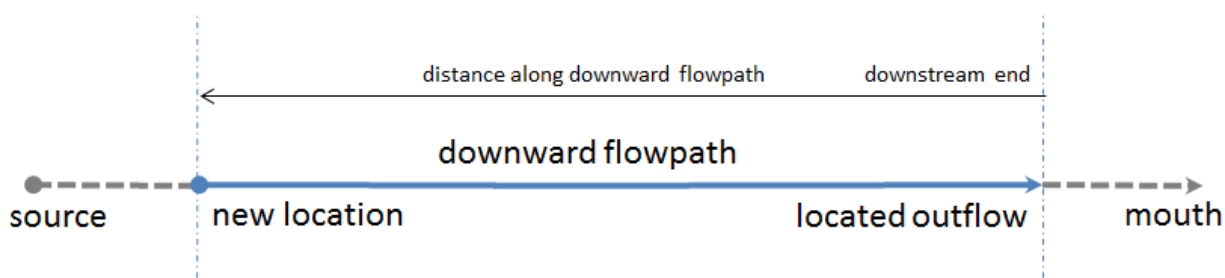


Figure 13. Inflow node referenced along a downstream flowpath

Network location of features realizing a catchment hydro nexus

In the case that the new network location is to be a hydro nexus in a pre-existing network, the already existing catchment would have to be split into catchments upstream and downstream of what was just a location, such as a stream gage, and becomes a hydro nexus that is associated with (realized by) a location (stream gage). Once inserted as a new hydro nexus, the upstream catchment would be realized as a flowpath between the location (stream gage) and the inflow of the now split catchment. Similarly, the downstream catchment would be realized by a flowpath between the new location and the outflow of the split catchment.

In this case, the unknown network position of the new location is known to be the inflow or outflow hydro nexus location. Figure 14 shows a newly introduced hydro nexus that now splits an existing flowpath. Because the new network location would now be a realization of the outflow hydro nexus of the upstream catchment and the inflow hydro nexus of the downstream catchment, its location is known to be the upstream or downstream end of the associated catchments' flowpaths.

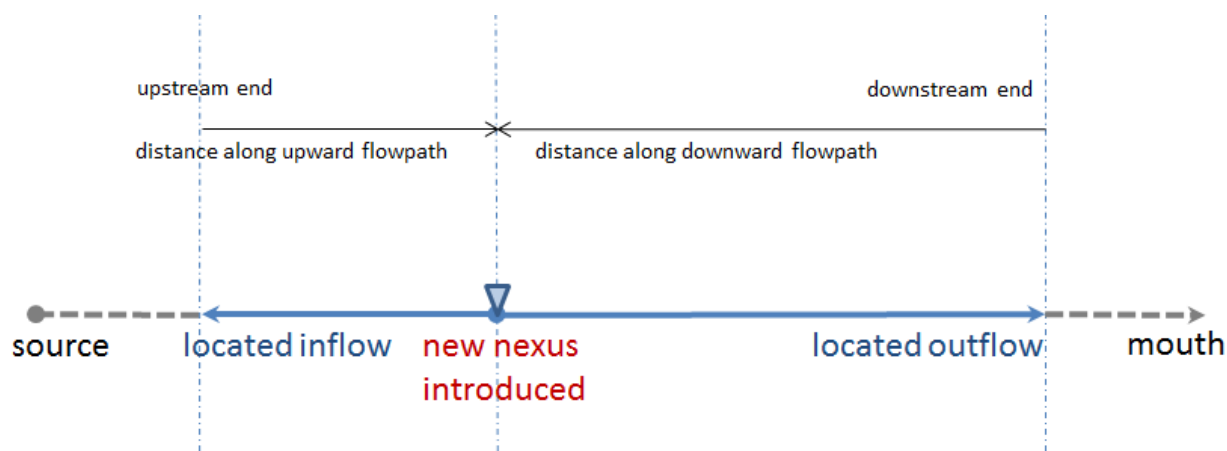


Figure 14. Newly introduced hydro nexus referenced along an upstream and downstream flowpath

Network location of features not realizing a hydro nexus

In the case that the existing catchment network is to be preserved, the feature being located will not become a hydro nexus with associated catchments. If the catchment and flowpath realizing the catchment is not split, the indirect position is expressed as part of the known distance between the inflow hydro nexus and the outflow hydro nexus, measured along the connecting flowpath. Figure 15 shows a new feature located along a flowpath. The location is expressed as the distance measured from the located outflow. Similarly, the new location could be located as a distance from an upstream hydro nexus measured along the flowpath.

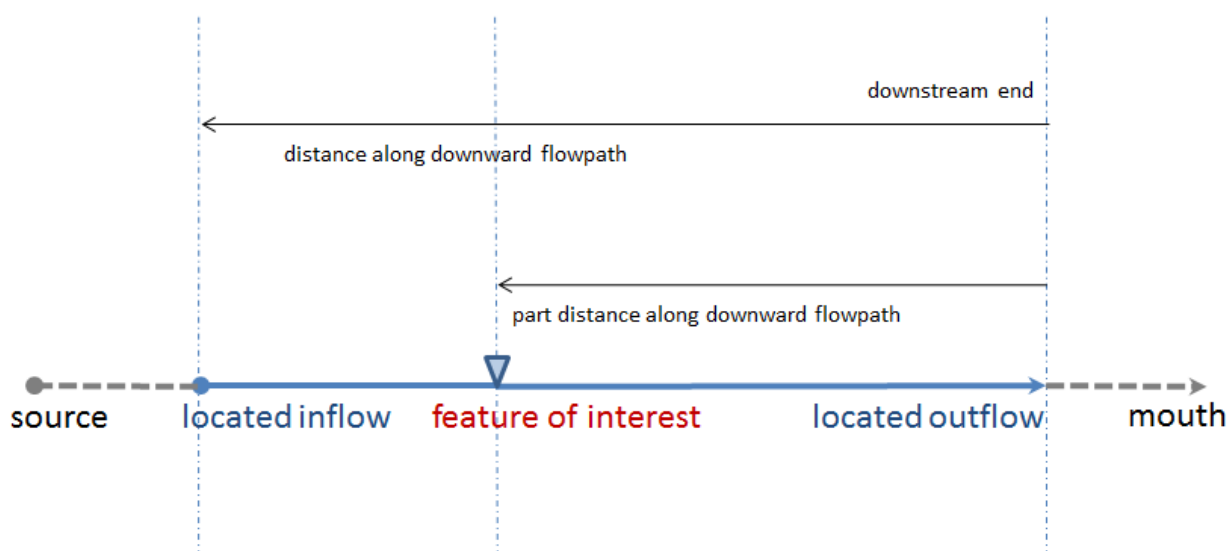


Figure 15. New location referenced along a downstream flowpath, expressed as part of the known distance from outflow node

Network location of features in reference to an already referenced location

While not common in hydrographic datasets, the known reference location does not have to be a

hydro nexus. If a hydro location has an already known network location, the indirect position can be expressed as part of the distance along the flowpath measured from such an already referenced location (located referent). Figure 16 shows a feature located along a flowpath in reference to a downstream referent that is located along the same flowpath relative to its outflow.

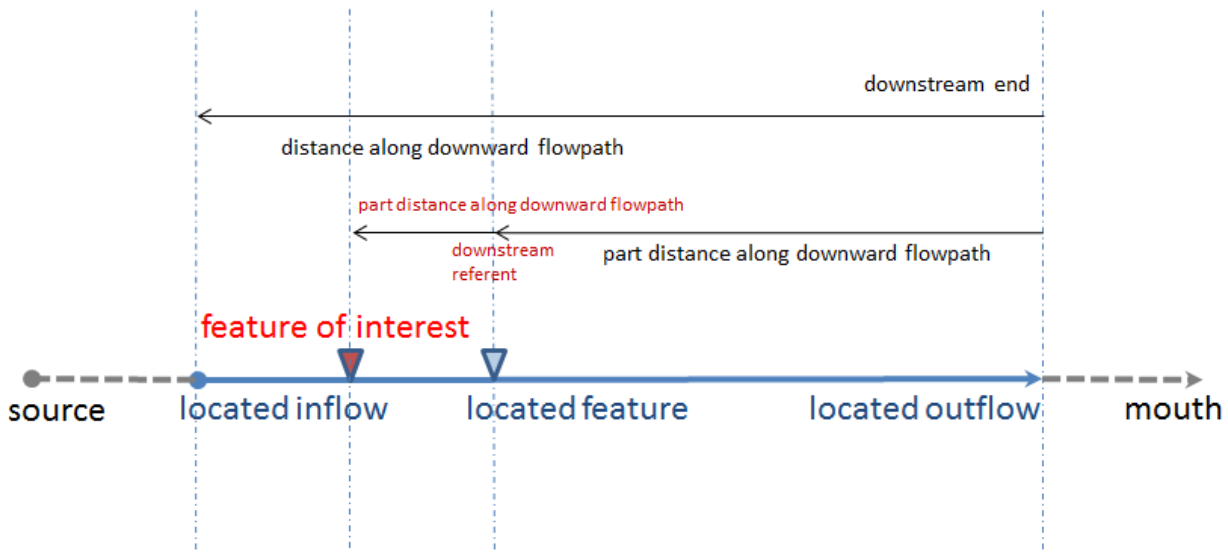


Figure 16. New location referenced along a downstream flowpath, expressed distance from a located feature, and finally as part of the known distance from outflow node

Location of features in a flowpath network

A feature of interest can be located somewhere along a particular network flowpath in a flowpath network realizing a network of catchments in two ways: 1) as a new inflow or outflow hydro nexus node bounding a (newly split) flowpath at one end and in reference to the other end, or 2) referenced upstream or downstream of a flowpath end or an already referenced location on a given flowpath. Figure 17, illustrates how a newly introduced network location can be located along an upstream flowpath, as an outflow node 'n1' referencing a known inflow node 'r2' graphically and with representative HY_Features UML. Figure 18 shows the location along a downstream flowpath referencing a known outflow node 'r1'.

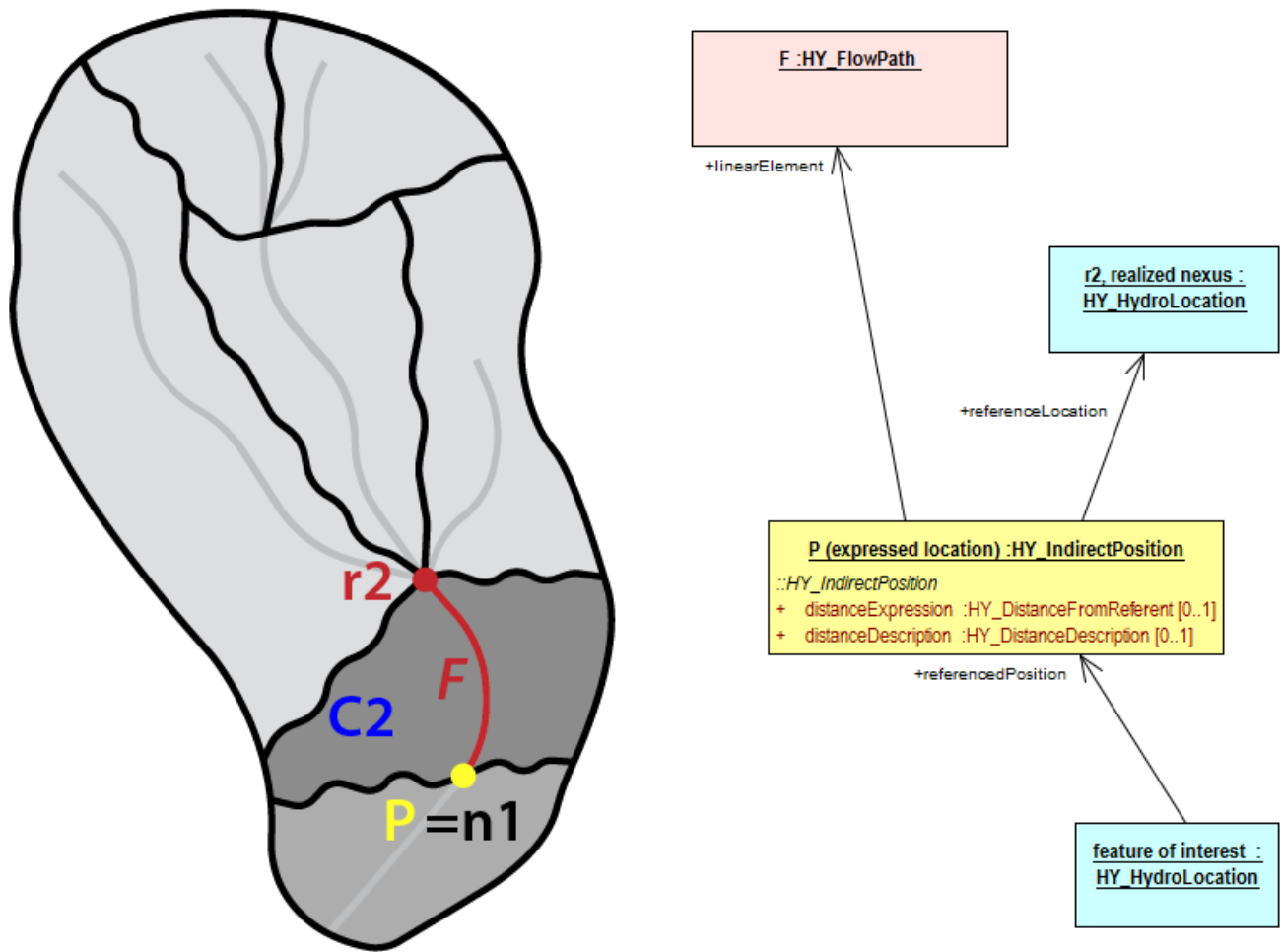


Figure 17. Position (yellow dot) of an outflow node referencing an inflow node, expressed as a measured distance from an upstream referent (red dot) and representative UML classes.

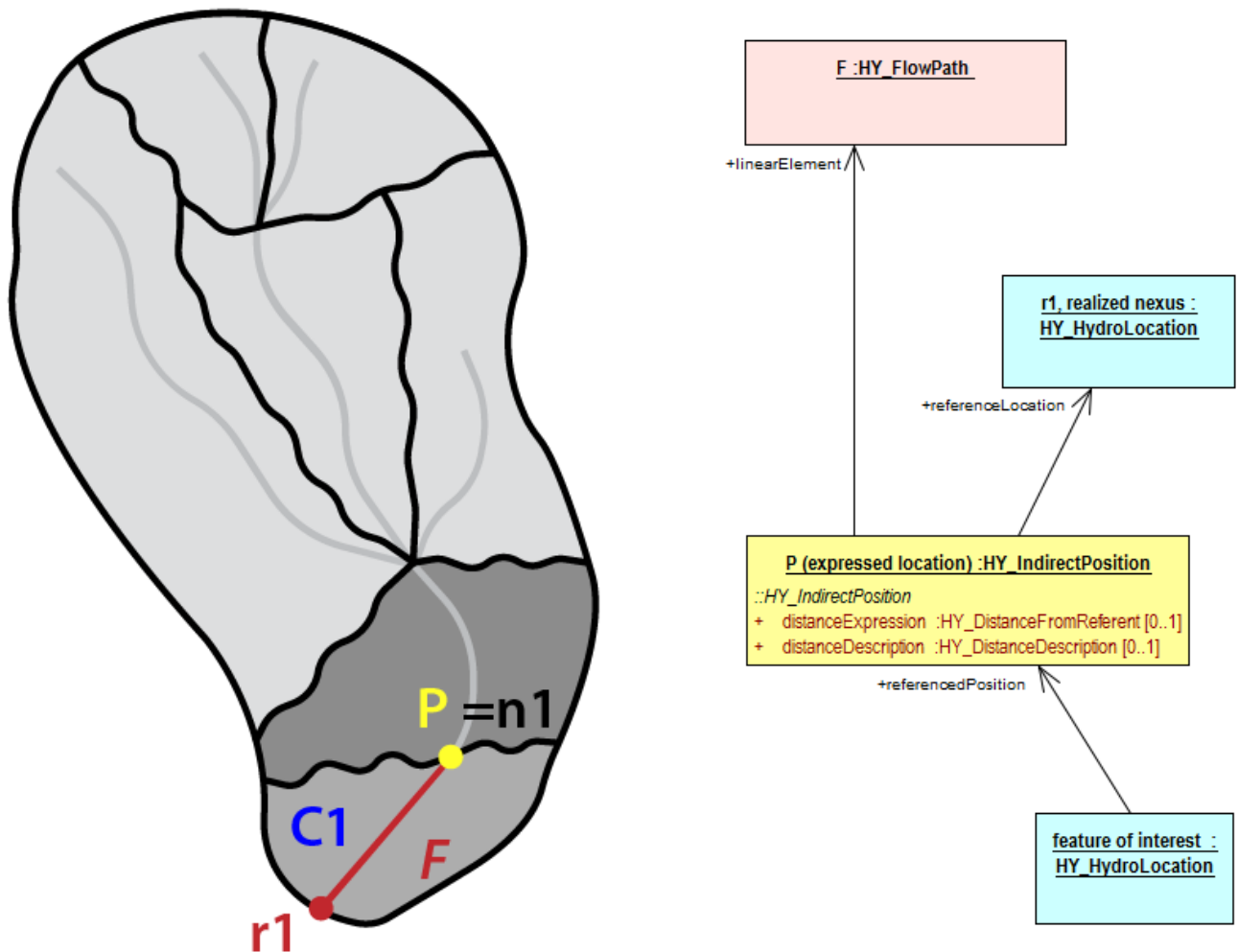


Figure 18. Position (yellow dot) of an inflow node relative to an outflow node, determined along a downstream flowpath, expressed as a measured distance from a downstream referent (red dot) and representative UML classes.

Figure 19 illustrates how the position of a feature can be determined as part the known distance between inflow and outflow nodes that bound a flowpath in upstream and downstream direction. The origin of the flowpath is set at one of its ends, and directed to the other. This approach is used in the case that the new location is not to be declared to be an inflow or outflow (hydro nexus node) of a catchment.

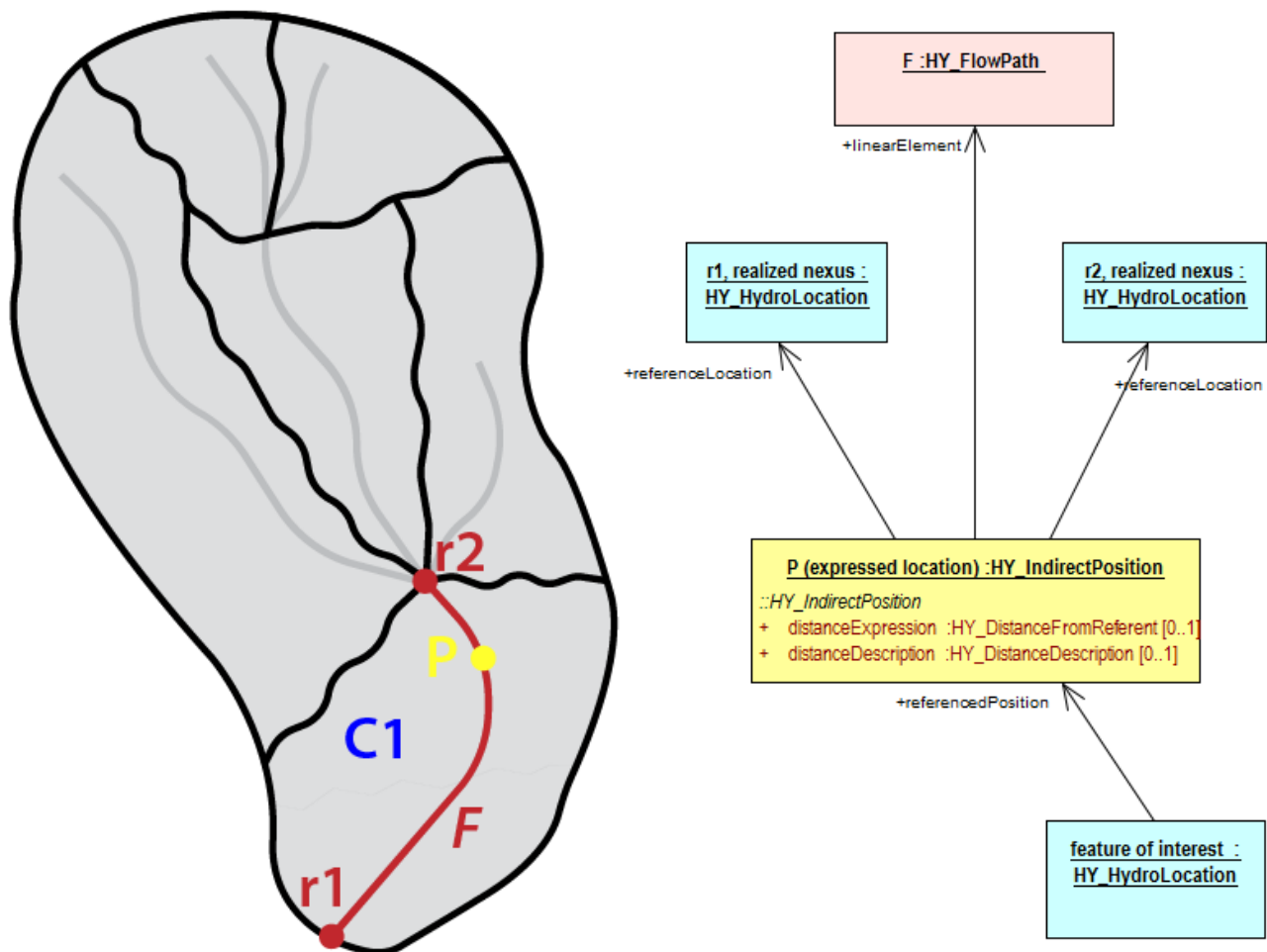


Figure 19. Intermediate Position (yellow dot) between known inflow and outflow nodes, expressed as distance from a located upstream or downstream referent (red dots).

The UML diagrams shown in Figure 17-19 illustrate that the river referencing system defined in this standard generally corresponds with the OGC standard model for Linear Referencing which is considered as the general framework to assign a position to a feature of interest along a hydrologic feature. The UML specifies fundamental properties of linear referencing along a flowpath to express the referenced location as a distance from a located referent, which may be the known inflow or outflow hydro nexus node or another referenced location.

Specific HY_Features classes supporting the referencing 'along a river' include HY_IndirectPosition, HY_DistanceFromReferent and HY_DistanceDescription described in section 7.3.3 of this standard

Table 1 provides a descriptive 'mapping' intended to provide a basic understanding of how the HY_Features river positioning system may specify the OGC standard Linear referencing model. The river positioning system is described in detail in section 7.3.3 of this standard, the OGC linear referencing model within the OGC Abstract Specification Topic 19, Linear referencing (aka ISO/FDIS19148:2011).

Table 1. HY_Features river positioning concepts comparable with the OGC Linear referencing model

HY_Features concept (internal HYF reference)	Description	OGC LR concept (internal LR reference)
River Referencing (leaf package), describing the system applied to place a hydrologic feature on a (linear) watercourse/stream feature. The feature location is specified as an indirect position expressed as distance along the watercourse on which the feature is to be placed.	A (hydrologic) feature of interest which is located along the locating one-dimensional flowpath referencing inflow and/or outflow already located on that flowpath, corresponds in general to the linear referencing along a linear element described in the OGC standard model for Linear referencing.	Linear Referencing model (leaf package), specification of a location relative to a linear element as a measurement along that element. This model describes allocation as position expressed as distance along a linear element.
Indirect Position (7.3.3.1), position expressing the location of a hydrologic feature (of interest) relative to the known location of another feature along an axis, which has <i>distance expression</i> , <i>distance description</i> , <i>referenceLocation</i> and an (already) <i>locatedReferent association</i> .	Feature that specifies a location through referencing along a 'linear' hydrologic feature. Indirect position is expressed as 'distance from referent' located at the upstream or downstream end of the flowpath, or as a term describing this distance.	Position Expression (6.2.2.1) specifies a linearly referenced location. Fundamental properties are 'linear element', 'distance expression' and 'LRM' [linear referencing method] describing the 'manner of measurement'.
Note: A <i>referencing method (feature type)</i> is not explicitly specified by <i>HY_Features</i> .	River referencing may be understood as a hydrology-specific referencing method applied to specify a location along a linear hydrologic feature. The river referencing results in an abstract, interpolative or descriptive value, which implies the usage of an appropriate method. The 'units' and 'type' properties of the referencing method are covered by the <i>HY_DistanceFromReferent</i> data type.	Linear Referencing Method (6.1.1.3) specifies how a linear element is measured. by 'name', 'type', 'units' and optional 'constraints'.

<p>Flowpath (7.3.2.6), realizes a catchment specifically as a path connecting the inflow and outflow of the catchment it realizes.</p> <p>Has a <i>realized catchment</i> association.</p>	<p>One-dimensional topological realization of a catchment forming the linear element along which an indirect position is determined.</p> <p>Topologically the flowpath can be understood as an edge bounded by catchment outlet nodes.</p>	<p>Linear Element (6.1.1.2) describes a feature that can be measured in a linear, one-dimensional, sense, incl. linear topological features such instances of directed edges.</p>
<p>Hydro Location (7.3.2.7), in the role of any hydrologic feature to be located on the network through referencing another hydrologically significant hydro location.</p> <p>Has a <i>referenced position</i> association.</p>	<p>Feature being linearly located, understood as 'feature event' that 'occurs' somewhere in the network of abstract catchments which is realized as a network of its linear flowpaths.</p> <p>A hydro location at distance 0 from the hydro nexus referent would be of type inlet or outlet and could be considered a realization of a hydro nexus.</p>	<p>Linearly located Feature (6.1.1.5) that is located along an associated locating feature using a linear referencing system. A feature linearly located specifies where along the locating feature the located feature occurs (feature event)</p>
<p>Hydro Location (7.3.2.7), in the role of an already located hydrologically significant referent that may realize the hydro nexus where a catchment interacts with another catchment,</p> <p>Has a <i>realized nexus</i> association</p>	<p>Feature being used as a reference, located at the upstream or downstream end of a flowpath which realizes the catchment whose hydro nexus is realized by the located referent.</p>	<p>Referent (6.1.1.4.2) specifies a known, already referenced location on the linear element 'from' where a distance can be measured.</p>
<p>Distance From Referent (7.3.3.3), distance from a located referent as an absolute or interpolative value.</p>	<p>Data type, expressing an indirect position value as distance along the flowpath 'measured' from a referent located at its upstream or downstream end, or elsewhere on the flowpath.</p> <p>The attribute names may reflect the 'type' property of LRM, the use of basic data types supports the 'units' property of LRM.</p>	<p>Distance Expression (6.1.1.4) specifies the measured value from the start, or another known location, on the linear element along that element.</p>

Distance	Description (Table B.2), describes the spatial relation between two locations.	Terms common in hydrology to describe the distance between a location being placed and a location being used as a reference. These terms may be used to express an offset the distance expression may have.	Offset (6.1.1.4.3) qualifies the distance expression with respect to locations not directly located on the linear element.
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6.6.2. Network navigation

Realizing catchments as topological edges bounded by hydro nexus nodes, a network of catchments may be traced upstream from the sea or a sink traversing from outflow node along catchment edge to inflow node of (multiple) upper catchments recursively. One can navigate all the way 'upstream' eventually arriving at the outflow node of the headwater catchments, which do not have an inflow hydro nexus. Starting at a spring, the catchment network can be traced in the 'downstream' direction, first to the single outflow node to which the catchment contributes then further downstream eventually arriving at an outflow node of an estuary or delta with no downstream catchment. In a given realization, a sequence of linear flowpaths, each realizing a catchment connected in the catchment network, may be drawn as streams or watercourses, which may or may not be geometrically connected in the representation.

When geometrically connected, the edge-node topology described above could be implemented based on a geometric network made up entirely of geometrically connected flowpaths. In some cases, the geometric network is all that is required to satisfy network navigation requirements. A second approach is to use the geometric network to create a topological edge-node network. In other cases, waterbodies and channel parts of a particular network may not form a well-connected network or be represented using different types of geometry, not suited to geometric network traversal. In such cases, a non-geometric topological (node-edge) realization, made up of catchments and hydro nexuses only could be used.

The network navigation approach described here corresponds generally to the standard network (navigation) model defined within ISO 19133: Location-based services - Tracking and navigation which is considered as a general framework to trace a network of catchments. Provided that a catchment is topologically realized comparable with the ISO topology model as directed edge (flowpath) and the hydro nexus as directed (inflow/outflow) node, the catchment network (as well as its hydrographic, geomorphologic or hydrometric realizations) can be navigated using the concepts of the ISO network (navigation) model.

In terms of network navigation, the hydrographic, channel or station network can be thought of as a set of junctions and links that connect these junctions. The realization of an inflow/outflow node is comparable with the 0-dimensional junction associating 'incoming and outgoing links', and the flowpath is comparable with 1-dimensional link associated with a 'start' and an 'end' set by the inflow or outflow node.

Table 2 provides a descriptive 'mapping' intended to provide a basic understanding of how the HY_Features network navigation may specify the Tracking and navigation model.

Table 2. HY_Features concepts comparable with the OGC Network navigation model

HY_Features concept	Description	ISO 19133 concept
Catchment realization network (6.3.1), aggregate of hydrologic features realizing a catchment.	The logical network of catchments interacting at hydro nexuses can be realized as networks of specific catchment realizations. The network of one-dimensional flowpaths connected by 0-dimensional inflow/outflow nodes can be understood as a navigation network.	Network (4.17), abstract structure consisting of a set of 0-dimensional objects called junctions, and a set of 1-dimensional objects called links that connect the junctions, each link being associated with a start (origin, source) junction and end (destination, sink) junction.
Flowpath (7.3.2.6), one-dimensional feature that realizes a catchment, and is associated to the <i>realized catchment</i> .	The topological realization, a directed edge bounded by inflow and outflow nodes can be understood as a connecting link between junctions.	Link (4.8), directed topological connection between two junctions consisting of an edge and a direction.
Hydro Location (7.3.2.5), hydrologic feature that can be a realization of an outlet, associated to the <i>realized hydro nexus</i> .	The topological (0-dimensional) realization as inflow or outflow node forming the boundary of the flowpath realizing the corresponding catchment. Can be understood as junction.	Junction (4.6), single topological node in a network with its associated collection of turns, incoming and outgoing links.

Chapter 7. Clause containing normative material

7.1. The HY_Features conceptual model

This standard defines the HY_Features conceptual model as a standard for the identification and description of hydrologic features reflecting both hydrologic significance and topological connectivity of hydrologic features. HY_Features formalizes the fundamental relationships between components of the hydrosphere describing the hydrosphere as a hierarchical network of hydrologically connected catchments, the various realizations a catchment may have and the organization of catchments, waterbodies or channels in networks.

The single concept that governs HY_Features is the hydrologically determined union of a catchment and its hydro nexus: any place on the land surface can be considered the hydro nexus of a corresponding catchment. Catchments and hydro nexuses together form the basis of networks of connected, usually named, hydrologic features. Other core concepts of HY_Features are: 1) an abstract idea of 'catchment' which has many possible geometric and/or topological feature realizations, 2) catchments realized as networks of waterbody features, and 3) linear referencing of river positions using a nominal main flowpath.

The conceptual model elements are grouped into three modules. A model implementation may include any or all feature concepts included in any module, include or exclude feature properties, and allow changing cardinality of one or more associations to 'nillable', expressing that these logically exist but are not realized in a particular implementation. Table 3 lists the modules, the leaf packages included in each, and the concepts reflected therein.

Table 3. HY_Features modules, concepts reflected, and leaf packages included

Application schema	Concepts reflected	Leaf packages included
HY_HydroFeature	fundamental properties and relationships between features governed by the physical laws of Hydrology, naming of hydrologic features, location of hydrologic features along a linear flowpath.	Named Feature Hydro Complex River Positioning System
HY_SurfaceHydroFeature	hydrologic features on the Earth's land surface without the complexity and detail of hydrologic and hydraulic models.	Network Hydrographic Network Water Body Types Storage
HY_HydrometricNetwork	hydrometric network of logically connected hydrometric features located on or along a hydrologic feature.	---

The conceptual model is expressed in the Geographic Information Conceptual Schema Language (ISO 19103:2005) based on the Unified Modeling Language (UML). The organization of the HY_Features hydrology model classes into modules, packages, and dependencies is shown in Figure 20.

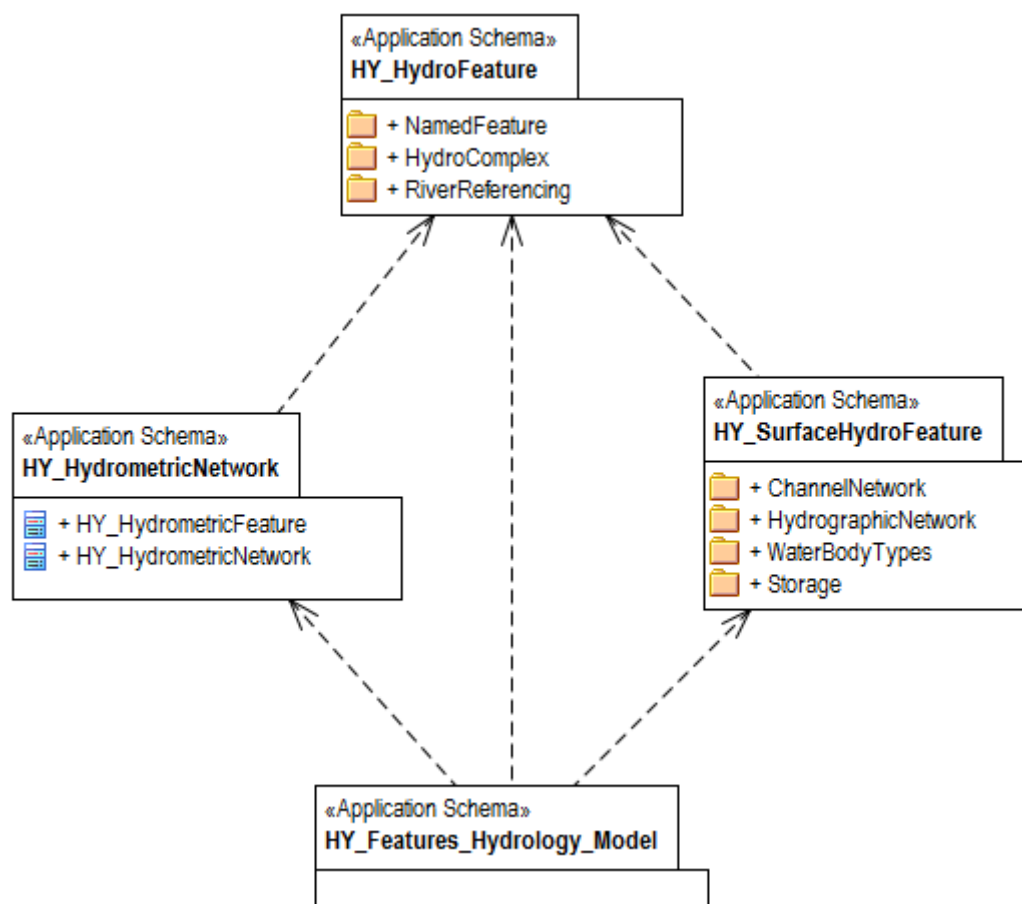


Figure 20. HY_Features modules and packages

7.2. HY_Features conceptual model conformance

Requirements Class	/req/hy_features_conceptual_model
Target types	1) Implementation Schema 2) Implementation Schema Mapping
Name	HY_Features Conceptual Conformance
Dependency	/iso/19103/
Dependency	/doc/AS/Topic1
Dependency	/doc/AS/Topic2
Dependency	/doc/AS/Topic19

If required, an implementation should use terms from the code lists in Annex B of this standard, defined specifically to conform to a terminology common in the hydrology domain. Note that alternative code lists may be used but should be related to the terms in Annex B.4 using an appropriate formalism.

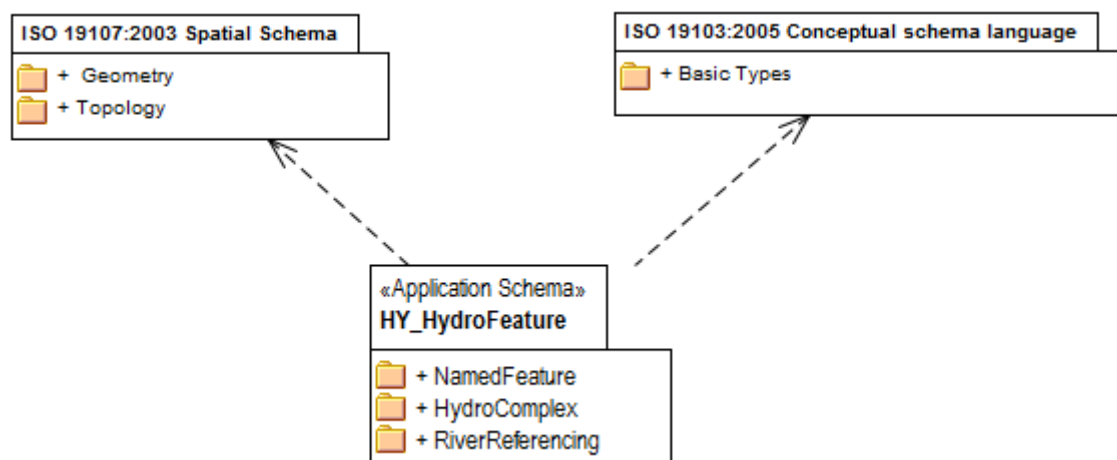


Figure 22. Hydro Feature – external dependencies

The HY_HydroFeature feature type is defined as hydrology-specific instance of the General Feature metaclass (as defined in the OGC General Feature Model, GFM), whose identity needs to be maintained and tracked through a processing chain from measurement to distribution of hydrologic information.

As an instance of the General Feature metaclass a feature type is identified by a unique identifier and typical properties. Typically, a hydrologic feature is additionally identified through names in common usage and through hydrologically significant characteristics.

The HY_HydroFeature feature type is specialized into more specific feature types, which specify additional properties and represent particular hydrologic phenomena (Figure 23).

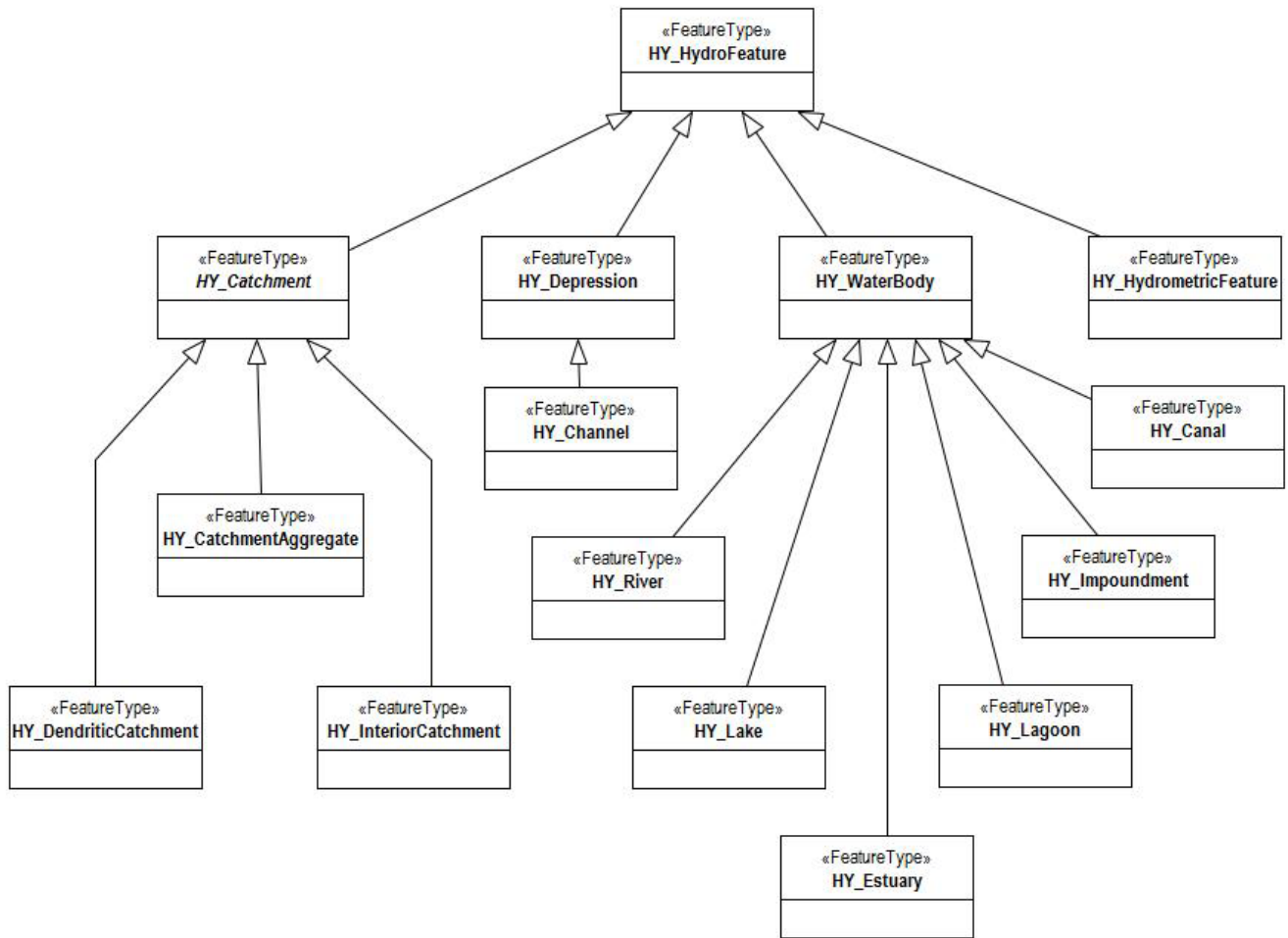


Figure 23. Hydrologic features describing separate aspects of hydrology phenomena

The definitions of HydroFeature feature types are rooted in the definitions documented in the WMO/UNESCO Glossary of Hydrology. They are applied regardless of their application context in respect to the Earth’s surface. For the purpose of testing the applicability of the HY_Features conceptual model in the context of surface water hydrology, the definitions in this standard refer to surface water hydrology. A conceptual model capturing the specifics of features associated with the groundwater domain is developed with reference to the OGC WaterML 2: Part 4 - GroundwaterML2 standard [6].

Providing a standard terminology for the typical relationships between hydrologic features allows the hydrosphere to be expressed in a consistent way across multiple data products, regardless of various spatial or temporal representations.

7.3.1. The Named Feature model

The Named Feature model (Figure 24) defines the HY_HydroFeature type as a basic feature to reflect the properties that all hydrologic features have, such as names in cross-jurisdictional and multi-lingual contexts. The HY_HydroFeature type has one association: *name*.

Table 4. HY_HydroFeature

Property	Concept or definition	Relation
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<i>name</i>	name given to the hydrologic feature in cultural, political or historical context	Association
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This links a HY_HydroFeature object to zero or more HY_HydroFeatureName objects.

The HY_HydroFeatureName type provides a pattern to handle cultural, political and historical variability of names. This supports the assignment of a referenceable name for all or parts of a hydrologic feature without necessarily having a formal model for the naming.

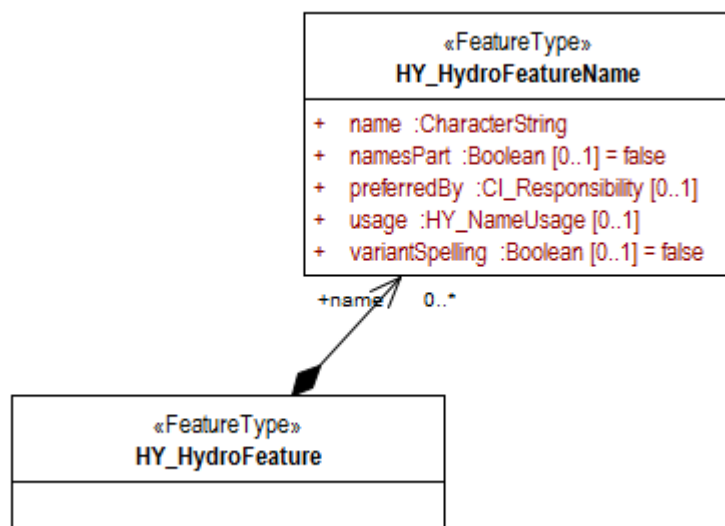


Figure 24. Named Feature (UML class diagram)

HY_HydroFeatureName carries five attributes: *name*, *namesPart*, *preferredBy*, *usage* and *variantSpelling*.

Table 5. HY_HydroFeatureName

Property	Concept or definition	Relation	Type
<i>name</i>	the individual name used in a country or region under the conditions of nation and language.	Attribute	CharacterString
<i>namesPart</i>	indicates whether the name applies to a part of feature only or not, using the Boolean value type.	Attribute	CharacterString

<i>preferredBy</i>	specifies that the name is the preferred name according to the named entity. The CI_Responsibility type may be used to further structure the information about the responsible party and their role.	Attribute	CharacterString
<i>usage</i>	expresses the kind of name usage in a specific community, using a term from the HY_NameUsage code list, or a controlled vocabulary. Alternative code lists may be used but should be related to the terms in Annex B.4 using an appropriate formalism.	Attribute	CharacterString
<i>variantSpelling</i>	indicates whether the name is a variant spelling or not using the Boolean value type.	Attribute	CharacterString

7.3.2. The Hydro Complex Model

The Hydro Complex model describes a collection of hydrologic features that form a hydrologically closed system. This includes the catchment, its inflow and outflow (conceptualized as hydro nexuses) as well as various realizations of catchment and hydro nexuses by typical hydrologic features. In this complex, the union of catchment and its common outlet determines the topological closure of an abstract catchment and its inflow and outflow hydro nexuses. The catchment topology pattern, which could, be expressed as a flowpath bounded by inflow and outflow nodes, is then applied to realize the connectivity in hydrographic networks, channel networks, or hydrometric networks.

The Hydro Complex model also allows catchments to be recognized through reference to a hydro nexus even if stream networks, catchment areas or catchment boundary are not available. It is intended that hydrological reporting applications may use this model without the full complexity and detail of scientific catchment models.

Catchment

The Catchment model conceptualizes the hydrologic determination of a catchment through inflow and outflow hydro nexus features with the role of getting flow from a contributing catchment, or providing inflow to a receiving catchment (Figure 25 and Figure 26). Conceptually, each catchment has an outflow hydro nexus, and any hydro nexus has a corresponding catchment, even if catchment and/or hydro nexus may not be present in a particular application. A catchment

interacts with upper and lower catchments via associated hydro nexuses, and ultimately contributes flow to the hydro nexus of a containing catchment. The catchment should be understood as the logical link between two hydro nexuses.

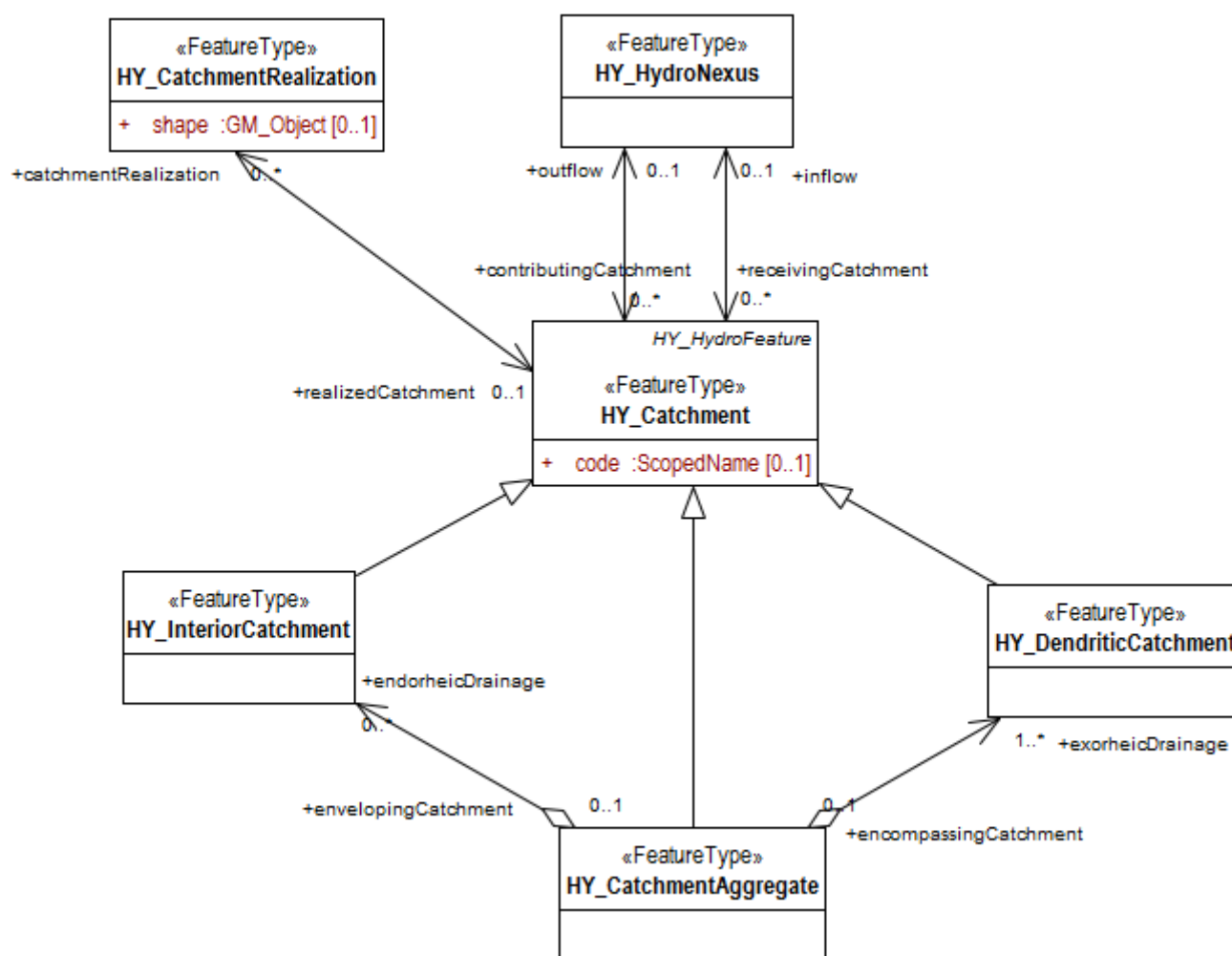


Figure 25. Catchment model (UML class diagram)

The HY_Catchment feature type captures the union of catchment and hydro nexus, and the multiple realizations of the holistic catchment concept. These realizations include both topological realizations, as well as their geometric representation. HY_Catchment may be further specialized with respect to catchment interaction.

The HY_Catchment feature type (Figure 26) specializes the general HY_HydroFeature type. Through generalization, HY_Catchment inherits the *name* property. It carries a *code* attribute and the associations: *outflow*, *inflow*, *containingCatchment*, *containedCatchment*, *conjointCatchment*, *upperCatchment*, *lowerCatchment*, *catchmentRealization*.

Table 6. HY_Catchment

Property	Concept or definition	Relation
<i>code</i>	unique identifier to the catchment in given context. The code attribute should be implemented using a controlled classification or coding system. Example: WMO Basin Codes.	Attribute

<i>outflow and inflow</i>	hydro nexus in terms of an outflow of the contributing catchment, or inflow to the receiving catchment. For a dendritic network of catchments, the outflow of a contributing catchment coincides with the inflow to a receiving catchment. This supports description of upstream-downstream relationships between catchments.	Association
<i>containingCatchment and containedCatchment</i>	nesting of catchments in a simple "is-in" containment hierarchy as typically used for nested organization of management and reporting units.	Association
<i>conjointCatchment</i>	catchment interacting with another catchment across an internal boundary, and contributing together with these to a single, common hydro nexus. This internal boundary may be a divide separating adjacent catchments, or a diffused divide between non-delineated sub-catchments within an encompassing catchment, or a fictive boundary between distant catchments. A dendritic network of catchments provided, where each catchment is determined by its single outflow, this association can be used to summarize diffused inflow into a catchment, as typical for headwater catchments, or spread outflow occurring for example in estuary catchments.	Association
<i>upperCatchment and lowerCatchment</i>	neighboring catchment immediately above or below of the catchment. This allows to trace the catchment network in an upstream direction from mouth to source, or downstream from source to mouth.	Association
<i>catchmentRealization</i>	topological or geographic feature which realizes the catchment concept.	Association

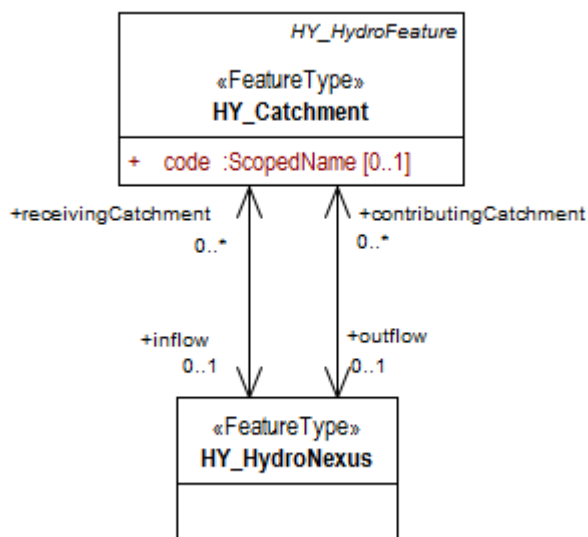


Figure 26. Catchment and hydro nexus (UML class diagram)

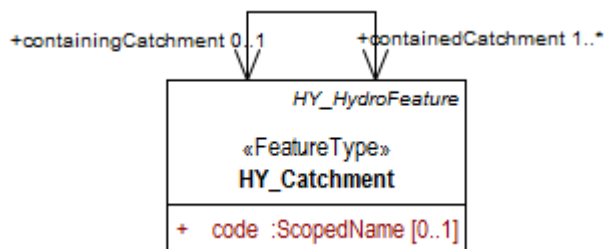


Figure 27. Containing / contained catchment (UML class diagram)

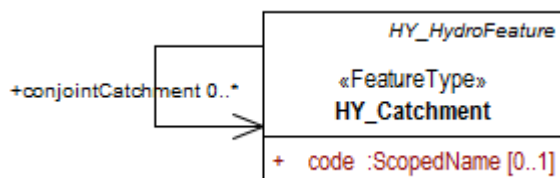


Figure 28. Conjoint catchment (UML class diagram)

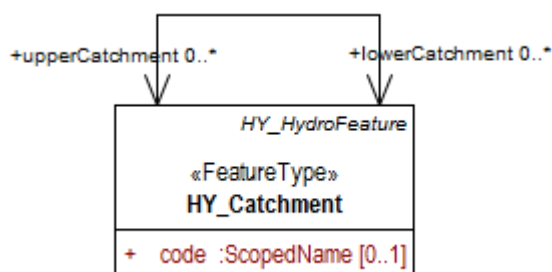


Figure 29. Upper / lower catchment (UML class diagram)

Catchment Aggregate

The **HY_CatchmentAggregate** feature type (Figure 30) specializes the **HY_Catchment** type as a set of non-overlapping dendritic and interior catchments arranged in an encompassing catchment. This can be used to describe multiple inflows into a catchment aggregate through several hydrologically discrete sub-catchments each with a single inflow, and contributing to a joined outflow of the catchment aggregate, including the 'nillable' outflow of interior catchments. Nillable is meant here to signify that the hydro nexus logically exists in the form of flow to the subsurface or atmosphere but is unknown in a given implementation.

Being a special type of the **HY_Catchment**, the catchment aggregate may be part of a containing catchment at the next higher level of hierarchy, which consists of similar-scale neighboring catchments. The catchment aggregate does not necessarily imply a series of nested containing catchments. It primarily allows navigation to the 'highest' level system (total drainage basin) as typically used for reporting purposes.

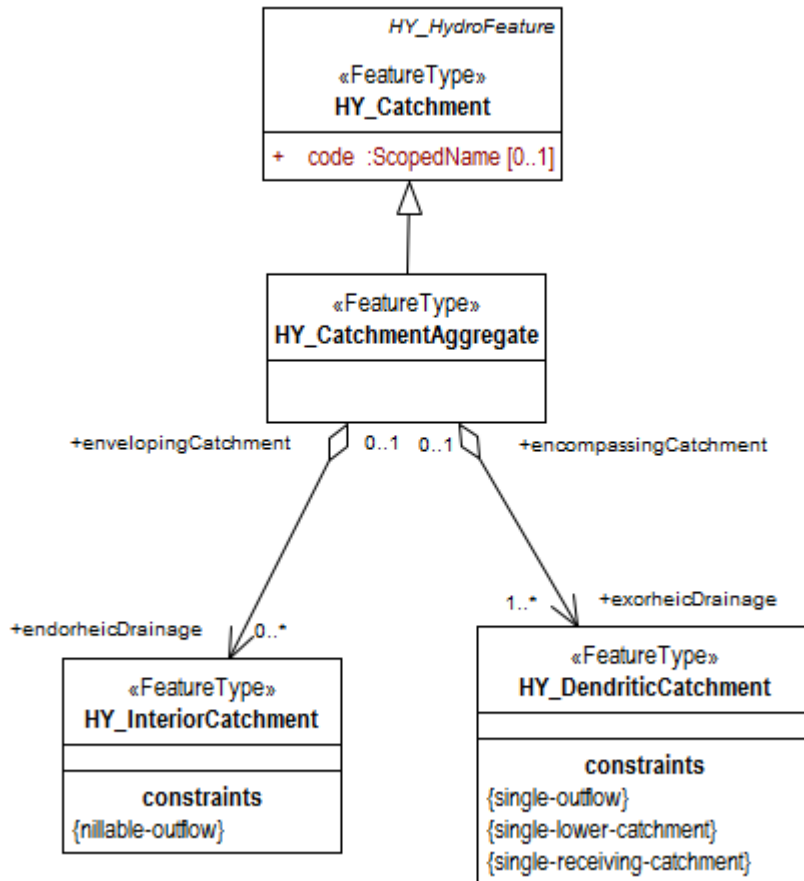


Figure 30. Catchment aggregate (UML class diagram)

HY_CatchmentAggregate inherits through generalization the *outflow*, *inflow*, *containingCatchment*, *containedCatchment*, *conjointCatchment*, *upperCatchment*, *lowerCatchment*, and *catchmentRealization* properties, as well as *exorheicDrainage* and *endorheicDrainage* associations.

Table 7. HY_CatchmentAggregate

Property	Concept or definition	Relation
<i>exorheicDrainage</i>	should be used to identify an exorheic-drained catchment which is permanently connected to the encompassing catchment.	Association
<i>endorheicDrainage</i>	should be used to identify an endorheic-drained catchment, which is not, but may be temporarily connected to the enveloping catchment.	Association

Dendritic Catchment

The HY_DendriticCatchment feature type (Figure 31) specializes the general HY_Catchment class as a catchment which is determined by a single common downstream catchment. It represents the catchment as the topological link between an inflow and an outflow. This allows catchments to be connected in a dendritic network by upstream-downstream relationships without knowing the complex hydrology between inflow and outflow. This concept requires a stable identifier purposefully assigned to the catchment and that catchments are delineated as a simple tree hierarchy.

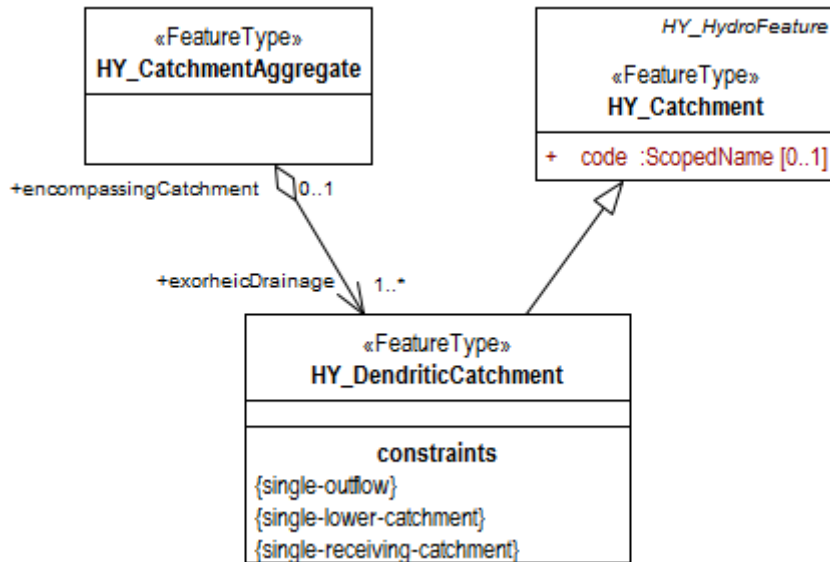


Figure 31. Dendritic catchment (UML class diagram)

HY_DendriticCatchment inherits from generalization the *code*, *outflow*, *inflow*, *containingCatchment*, *containedCatchment*, *conjointCatchment*, *upperCatchment*, *lowerCatchment*, and *catchmentRealization* properties, as well as an *encompassingCatchment* association. The dendritic nature of this feature is enforced through *single-outflow*, *single-receiving-catchment* and *single-lower-catchment* constraints.

Table 8. HY_DendriticCatchment

Property	Concept or definition	Relation
<i>encompassingCatchment</i>	identifies the catchment encompassing one or more dendritic catchments contributing together flow to the common outlet.	Association
<i>single-Outflow</i>	defines a cardinality of '1' indicating that the dendritic catchment contributes to one and only one single outflow. A single outflow can be unknown (nillable) in a particular application, for example in the case of a delta to which a virtual outflow is assigned. An implementation SHOULD unambiguously specify whether the outflow exists, or is nillable.	Constraint
<i>single-Receiving-Catchment</i>	defines a cardinality of '1' indicating that one and only one single catchment receives flow via the outflow of the catchment. A receiving catchment can be unknown (nillable) in a particular application, for example in the case of the last catchment in a hierarchy, contributing flow directly to the ocean or an internal sink. An implementation SHOULD unambiguously specify whether the receiving catchment exists, or is nillable.	Constraint

<i>single-Lower-Catchment</i>	defines a cardinality of '1' indicating that one and only one lower catchment exists neighboring the catchment. A lower catchment can be unknown (nillable) in a particular application, for example in the case of the last catchment in a hierarchy, contributing flow directly to the ocean or an internal sink. An implementation SHOULD unambiguously specify whether the lower catchment exists, or is nillable.	Constraint
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Interior Catchment

The HY_InteriorCatchment feature type (Figure 32) specializes the general HY_Catchment class as a catchment which is generally not connected to other catchments. This class describes the interior catchment as a catchment enveloped by other catchments to which it may temporarily contribute. While the interior catchment concept precludes flow to neighboring surface catchments, holistically it is a candidate for establishing connections to groundwater or atmospheric systems.

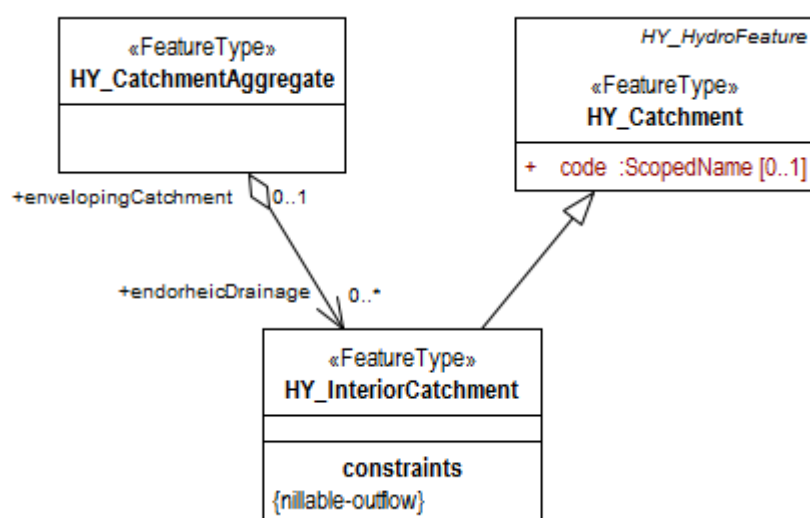


Figure 32. Interior catchment (UML class diagram)

HY_InteriorCatchment inherits from generalization the *code*, *outflow*, *inflow*, *containingCatchment*, *containedCatchment*, *conjointCatchment*, *upperCatchment*, *lowerCatchment*, and *catchmentRealization* properties, as well as an *envelopingCatchment* association. A *nillable-outflow* constraint emphasizes the non-existing outflow.

Table 9. HY_InteriorCatchment

Property	Concept or definition	Relation
<i>envelopingCatchment</i>	identifies a catchment surrounding the interior catchment.	Association
<i>nillable-outflow</i>	defines a cardinality of '0' indicating the non-existent outflow.	Constraint

Hydro Nexus

The HY_HydroNexus feature type (Figure 33) conceptualizes a hydrologically determined nexus of a

corresponding catchment (Figure 26). The hydro nexus represents the place where a catchment interacts with another catchment, i.e. where the outflow of a contributing catchment becomes 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. This includes the topological realization as a node on the one-dimensional flowpath (edge) in terms of a topological 'boundary'.

Placed topologically relative to a catchment which links inflow and outflow, a hydro nexus has a position relative to another hydro nexus that is 'fixed' in the network by the catchments it is associated with. Additionally, the union of catchment and hydro nexus(es) can be used to define a linear river reference system, where an inflow or outflow node is the origin and the flowpath realizing the catchment is the linear element along which a position can be determined.

Although conceptually, a given catchment will always have a corresponding outflow hydro nexus, 0..1 cardinality is used for HY_HydroNexus in the role of outflow to provide an opportunity to use the catchment hierarchy model in implementations where the (always logically existing) nexus is not known. If required, an implementation may specify it to be 1..1.

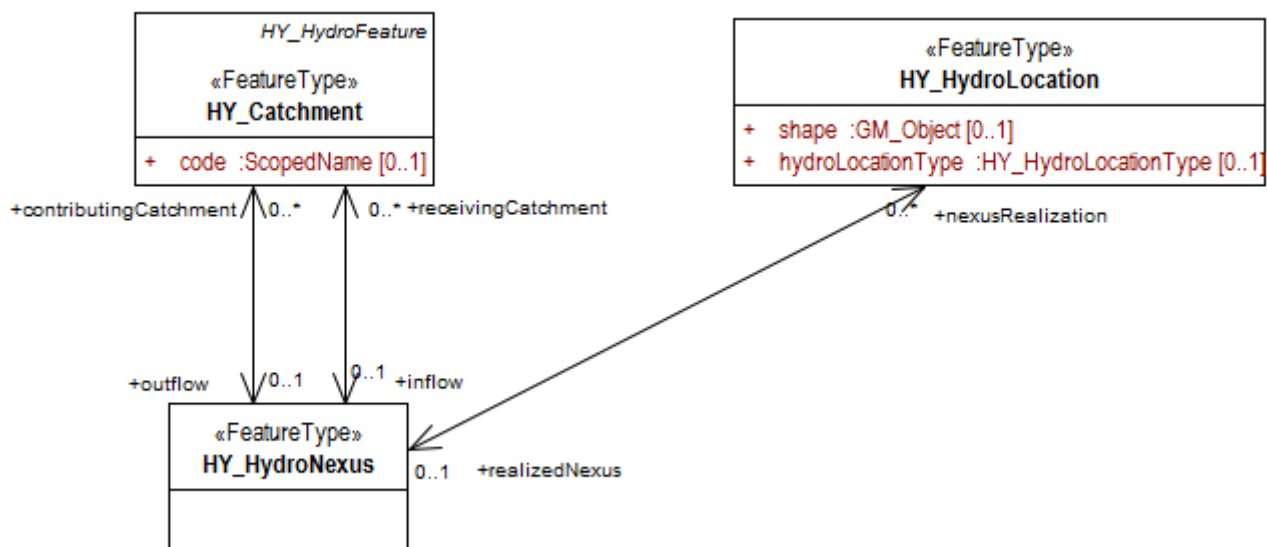


Figure 33. Hydro nexus (UML class diagram)

HY_HydroNexus carries the associations: *contributingCatchment*, *receivingCatchment*, and *nexusRealization*.

Table 10. HY_HydroNexus

Property	Concept or definition	Relation
<i>contributingCatchment</i>	identifies the catchment that contributes flow to this hydro nexus. This allows connection of a catchment's outflow to an identified inflow and to determine its position through referencing the inflow.	Association

<i>receivingCatchment</i>	identifies the catchment that receives flow from this hydro nexus. This allows connection of a catchment's inflow to an identified outflow and to determine its position through referencing the outflow.	Association
<i>nexusRealization</i>	identifies a hydrologic feature which realizes the hydro nexus. A topological nexus realization is of lower dimension than the realization of the corresponding catchment. Example: an outflow node realizing the nexus would be of lower dimension than the flowpath edge realizing the contributing catchment.	Association

Catchment Realization

The HY_CatchmentRealization feature type (Figure 34) is based on the idea that there are multiple hydrology-specific perspectives of the holistic catchment concept that are used to describe a catchment as a unit of study shared across sub-domains and studies.

A given catchment realization exists within a hydrologic complex in that, if a catchment realization exists, it exists in the same hydrologic complex as the catchment it realizes. In this way, any realization of a catchment has the same hydrologic determination of the catchment it realizes. If a catchment is connected with other catchments via inflow and/or outflow hydro nexuses, its realizations are also connected. A realization of the logical catchment is always of higher topological dimension than the realization of the corresponding hydro nexus topological boundary. For example, a linear flowpath realizing a catchment may be understood as an edge between inflow and outflow nodes; the areal realization of a catchment as a face bounded by linear inflow and outflow.

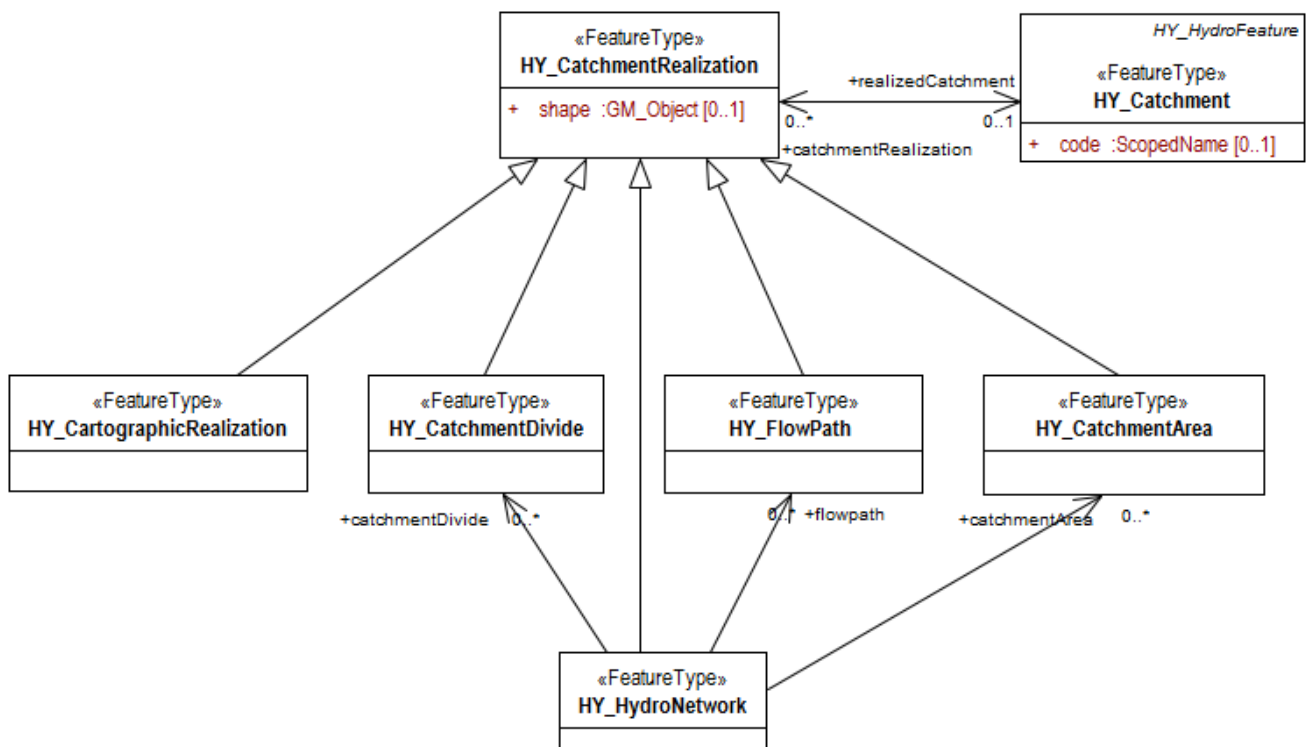


Figure 34. Catchment realization and its specialization (UML class diagram)

The catchment realization features defined in this standard refer to objects on the land surface for the purpose of surface water hydrology. In other contexts, other types of catchment realization may exist. Catchment realizations that do not conform to those defined in this standard, for instance realizations in 3- or 4-dimensional perspectives, may be implemented using the general `HY_CatchmentRealization` type. `HY_CatchmentRealization` carries a *shape* attribute and a *realizedCatchment* association.

Table 11. *HY_CatchmentRealization*

Property	Concept or definition	Relation
<i>shape</i>	geometric representation of a particular catchment realization.	Attribute
<i>realizedCatchment</i>	identifies the one and only one catchment that is realized by a particular feature. Referencing the hydrologic complex containing the catchment and all of its realizations, supports a catchment's existence to be recognized and linked to multiple realizations without the complexity and full detail of a scientific model. By referencing the catchment topology, topological relationships can be established and common identifiers assigned.	Association

The **HY_Flowpath** feature type realizes a catchment specifically as a path connecting the inflow and outflow of the catchment it realizes. `HY_Flowpath` specializes `HY_CatchmentRealization` with respect to an implied linear geometric representation including a straight or curved line. Topologically, the flowpath connects the inflow and outflow of the catchment, and is understood as an edge bounded by an inflow node and an outflow node, and corresponding to left-bank and right-bank catchment faces. Hydrologically, the flowpath is a line describing a moving particle of water. Through generalization, `HY_Flowpath` inherits the *shape* and the *realizedCatchment* properties. The optional *shape* of the flowpath is usually a single curve.

The **HY_CatchmentDivide** feature type realizes a catchment specifically as catchment boundary connecting the inflow and outflow of the catchment it realizes, whereby inflow and outflow may overlay. Implying a linear geometric representation, a catchment boundary is topologically understood as an edge bounded by inflow node and outflow nodes, and corresponding to left-bank and right-bank catchment faces inside of the boundary. Hydrologically, the boundary refers to the summit line separating adjacent catchments. Through generalization, `HY_CatchmentDivide` inherits the *shape* and the *realizedCatchment* properties. The *shape* of the catchment divide may be implemented as a composition of succeeding curves or a polygon ring.

The **HY_CatchmentArea** feature type realizes a catchment specifically as a catchment area connecting the inflow and outflow of the catchment it realizes. `HY_CatchmentArea` specializes `HY_CatchmentRealization` with respect to an implied areal geometric representation. Topologically, the catchment area connecting the inflow and outflow of the catchment is a face bounded inwards by an inflow edge and outwards by an outflow edge. Hydrologically, catchment area refers to the area having a common outlet for its runoff. Through generalization, `HY_CatchmentArea` inherits the *shape* and the *realizedCatchment* properties. The optional *shape* of the catchment may be implemented as a surface.

The **HY_HydroNetwork** feature type realizes a catchment as a network of connected hydrologic features. Such a network realizes the hierarchical network of logically connected catchments contained in a larger catchment. It may be a sequence of flowpaths, an aggregate of catchment areas or a mesh of catchment divides. HY_HydroNetwork feature type specializes HY_CatchmentRealization. Through generalization it inherits the *shape*, the *realizedCatchment* properties, and carries the associations *flowpath*, *catchmentDivide* and *catchmentArea*. The optional *shape* of the HY_HydroNetwork is usually given through the individual geometries of the network parts.

Table 12. HY_HydroNetwork

Property	Concept or definition	Relation
<i>flowpath</i>	flowpath that participates in the network.	Association
<i>catchmentDivide</i>	catchment boundary that participates in the network.	Association
<i>catchmentArea</i>	catchment area that participates in the network.	Association

The HY_CartographicRealization feature type realizes a catchment as a set of separate cartographic layers or maps, displaying a network of hydrologic features which may be connected at the representation level, or not. Specializing HY_CatchmentRealization, it inherits through generalization the *shape* attribute and the *realizedCatchment* association.

Hydro Location

The HY_HydroLocation feature type (Figure 35) conceptualizes the idea that a hydro nexus can be realized by practically any feature of interest. The hydro nexus concept is used to define the hydrologic determination of a catchment but, like the catchment concept, does not have inherent realization(s). Any hydrologically significant feature that can be identified as (said to be) the outlet of a catchment may realize the hydro nexus. Typically, this will be a permanent, stable location that is fixed and/or referenced by coordinates.

Landmarks such as confluences, points corresponding to vertical sections, or the position of a monitoring station on a river are typical realizations of the hydro nexus. Other kinds of hydro nexus realizations that don't carry normal surface water characteristics as defined in this standard, e.g. a spring where groundwater enters the surface, an arbitrary point projected onto the surface, or a nexus that collects many disjoint locations may use or specialize the general HY_HydroLocation type.

Topologically, the HY_HydroLocation should be understood to be the boundary of the corresponding catchment, and always of lower topological dimension than the catchment. Even though the topological realization of a hydro nexus is typically as a node between catchment edges, a nexus realization may also have any geometric representation, including a single point.

In many cases, HY_HydroLocations are known but corresponding catchments and hydro nexuses are not defined. For example, stream gages that are part of a catchment dataset whose hydro nexus features are realized by confluences. Both the stream gages and confluences are

HY_HydroLocations, but the stream gages' hydro nexus features are not defined. Using this concept, HY_HydroLocation is expected to be used to link between datasets that have catchments delineated for different HY_HydroLocations.

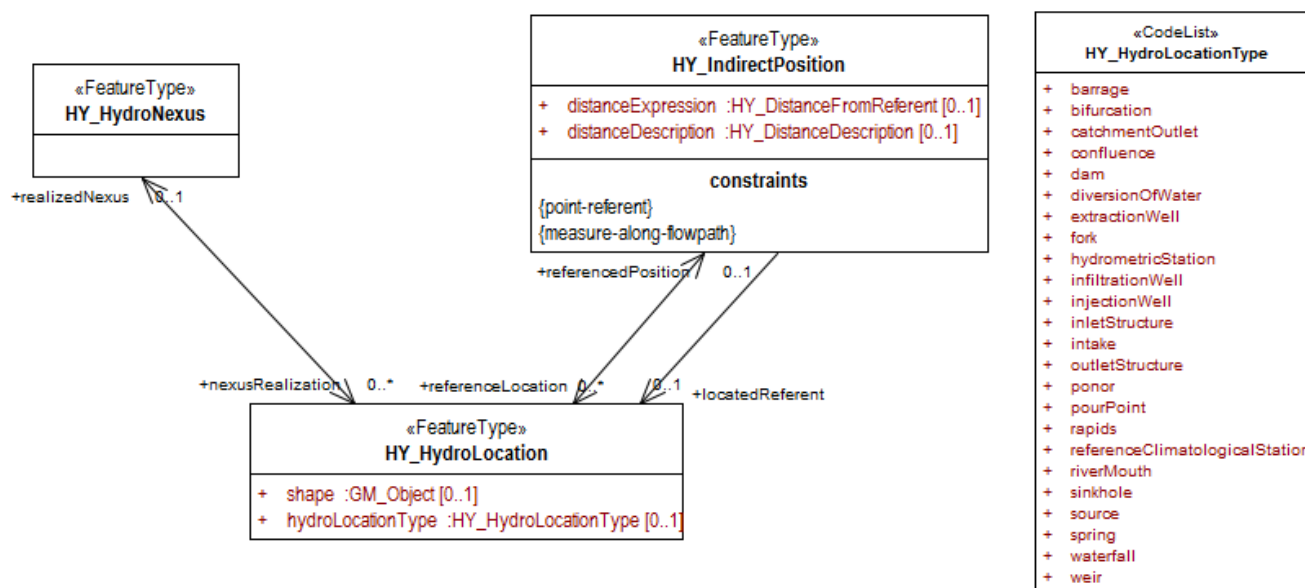


Figure 35. Hydro Nexus Realization - HydroLocation (UML class diagram)

HY_HydroLocation carries two attributes: *shape* and *hydroLocationType*. It has *referencedPosition* and *realizedNexus* associations implying the *hydro-complex* feature collection.

Table 13. HY_HydroLocation

Property	Concept or definition	Relation
<i>shape</i>	geometric representation of the realized nexus.	Attribute
<i>hydroLocationType</i>	expresses the type of the realized nexus, using a term from the HY_HydroLocationType code list, or a controlled vocabulary. Alternative code lists may be used but should be related to the terms in Annex B.1 using an appropriate formalism.	Attribute
<i>referencedPosition</i>	position expressed as measured or otherwise described distance from a known, already located referent. Commonly, this is used to locate a feature of interest such as a hydrometric station in relation to a catchment's outlet fixed by co-ordinates.	Association
<i>realizedNexus</i>	identifies the single nexus that is realized by a particular feature. Referencing the hydrologic complex containing the hydro nexus and all of its realizations, enables an arbitrary feature of interest to be recognized as an outlet of a catchment, and to be placed using the river referencing model defined in this standard.	Association

7.3.3. The River Referencing model

The River Referencing model (Figure 36) provides a simple model to place a feature of interest 'on a

river'. It introduces the concept of indirect position where a position is determined relative to an already established reference location. This model defines a linear river referencing system whose linear shape is given by a flowpath realizing the catchment between its inflow and outflow. It is important to note, that each catchment has its own reference system, which defines the start (origin) and the orientation of the linear flowpath (axis) along which the distance from a known referent can be measured. An implementation SHOULD unambiguously specify whether the direction of the measure (from referent) is with the catchment-specific orientation of the flowpath, or opposite to this.

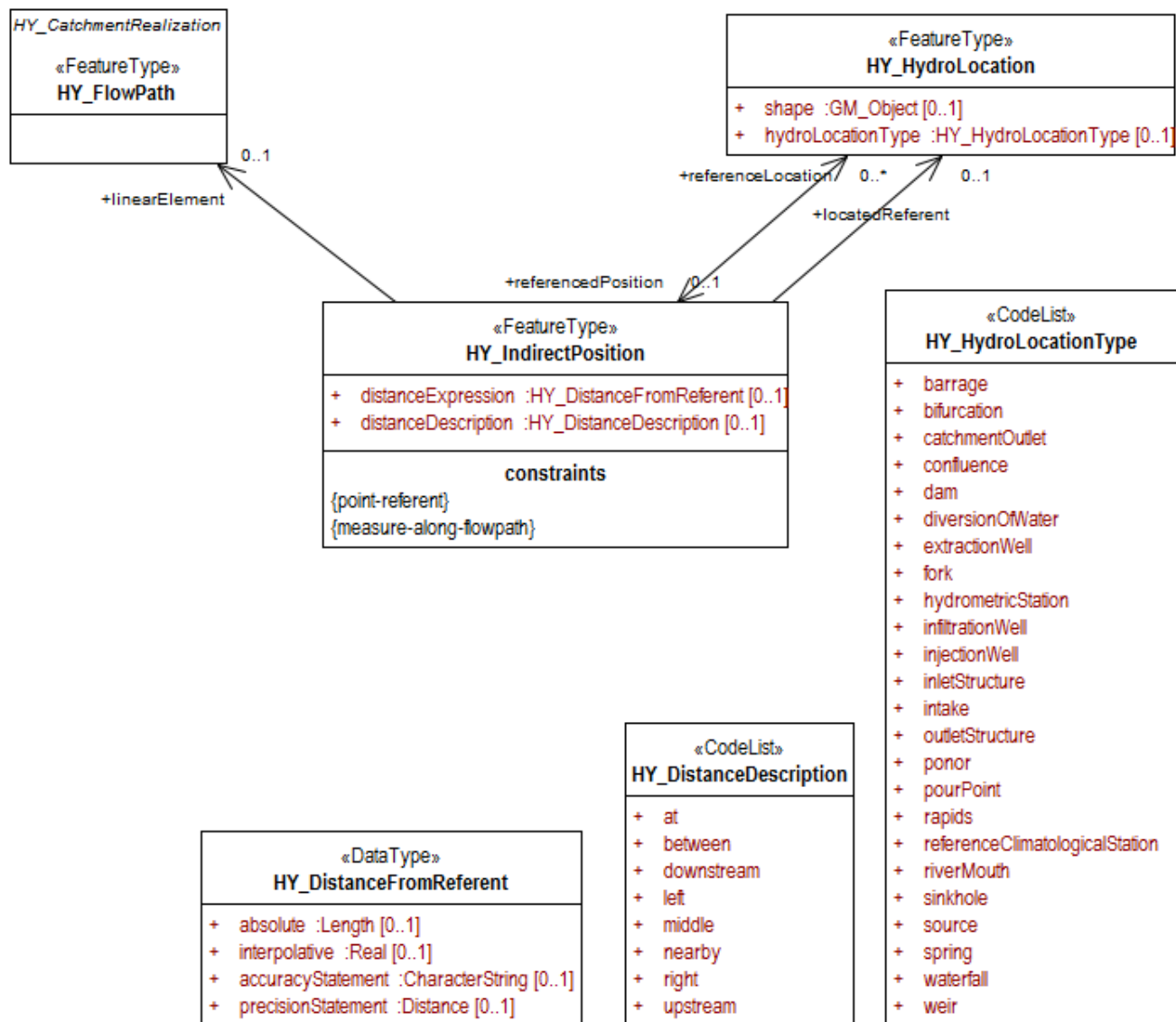


Figure 36. River Referencing (UML class diagram)

The River Referencing system uses the one-dimensional topological realization of catchment within the implied hydrologic complex such that the feature to be placed and the already located referent are nodes on the boundary of the same flowpath. Given that a flowpath realizes a catchment between inflow and outflow nodes, the feature of interest is placed some distance along a flowpath, while the location being used as a reference location is located at the upstream or downstream end of the flowpath. Using located referents in both directions allows placement of a feature of interest a percentage of the distance along a flowpath even if the realized catchment is not explicitly delineated.

Indirect Position

The HY_IndirectPosition feature type defines the location referenced along an axis, without the necessity of a geometric realization. Indirect position uses a catchment-specific reference system which defines the flowpath as the required linear element along which the position is determined. The indirect position is then expressed as the distance from the upstream and/or downstream end of the flowpath, or from a referent that is already located on that flowpath.

The (indirect) position of an outflow node referenced along an upstream oriented flowpath (Figure 17) can be expressed as the distance from an upstream inflow node located on that flowpath, while the (indirect) position of an inflow node referenced along a downstream oriented flowpath (Figure 18) can be expressed as distance from a downstream outflow node located on the flowpath. An 'intermediate' position referencing known inflow and outflow nodes bounding a flowpath at both ends (Figure 19) can be expressed as part of the distance along the entire flowpath, measured from the upstream end of an upstream flowpath, and/or from the downstream end of a downstream flowpath. A position referencing an already referenced location on the flowpath can be expressed as part of the distance along the entire flowpath, measured from the 'located referent'.

HY_IndirectPosition carries the *distanceExpression*, and *distanceDescription* attributes, and has *linearElement*, *locatedReferent* and *referenceLocation* associations. A *point-referent* constraint emphasizes the topological relationship between the linear element and point representation of the reference location and a *measure-along-flowpath* constraint defines the flowpath as the linear element to be used whenever a position is expressed as a distance from a referent.

Table 14. HY_IndirectPosition

Property	Concept or definition	Relation
<i>distanceExpression</i>	absolute or interpolative value of the distance from the feature being used as a reference, including an indication of accuracy and precision of the absolute value. An implementation may use the HY_DistanceFromReferent (data type) referencing basic types. Alternatively, the types described in ISO 19103: Conceptual Schema may be used.	Attribute
<i>distanceDescription</i>	term describing the distance from the feature being used as a reference. An implementation may use the HY_DistanceDescription code list. Alternatively, the types described in ISO 19103: Conceptual Schema may be used. Alternative code lists may be used but should be related to the terms in Annex B.2 using an appropriate formalism.	Attribute
<i>linearElement</i>	one-dimensional catchment realization, flowpath, used as the linear element along which a position is determined. To describe the linear axis in detail, including the unit of measure, an implementation may use the types described in ISO 19103: Conceptual Schema.	Association

<i>locatedReferent</i>	identifies an already referenced location such as a catchment outlet relative to which a position may be assigned to a feature of interest.	Association
<i>referenceLocation</i>	identifies the permanent reference location, usually an existing inflow or outflow hydro nexus relative to which a position is assigned to a hydro location feature of interest.	Association
<i>point-Referent</i>	defines that whenever a linear element exists, the referent should be recognized as a point. Geometrically represented as a point, the indirect position will support a direct position fixed by coordinates.	Constraint
<i>measure-Along-Flowpath</i>	defines that whenever a distance expression exists, the linear element should be recognized as a flowpath to support the geometric representation as a curve that can be measured as length and expressed by an appropriate unit of measure.	Constraint

Distance from Referent

The HY_DistanceFromReferent data type provides the distance from a located referent as an absolute or interpolative value, including simple statements on accuracy and precision of the measured position.

Table 15. HY_DistanceFromReferent

Property	Concept or definition	Relation
<i>absolute</i>	geometric expression of the distance from a located referent. An implementation may use the types described in ISO 19103: Conceptual Schema.	Attribute
<i>interpolative</i>	interpolative expression (percentage) of the distance from a located referent. An implementation may use the types described in ISO 19103: Conceptual Schema.	Attribute
<i>accuracyStatement</i>	simple statement whether the distance value agrees with the value accepted as being true. This statement assumes that all known corrections have been applied. An implementation may use the types described in ISO 19103: Conceptual Schema.	Attribute
<i>precisionStatement</i>	simple statement about the smallest unit of division on the scale of measurement. An implementation may use the types described in ISO 19103: Conceptual Schema.	Attribute

7.4. Surface Hydro Feature concepts

The Surface Hydro Feature application schema provides common concepts of hydrologic features occurring on the land surface and specifies the core concepts defined in the abstract Hydro Feature application schema. This will enable contextually linked information models to build relationships between multiple realizations of the same catchments. Typical realizations of the catchment concept and hydro nexuses can be described in a consistent way using standard terminology for the relationships between surface water features defined in this application schema.

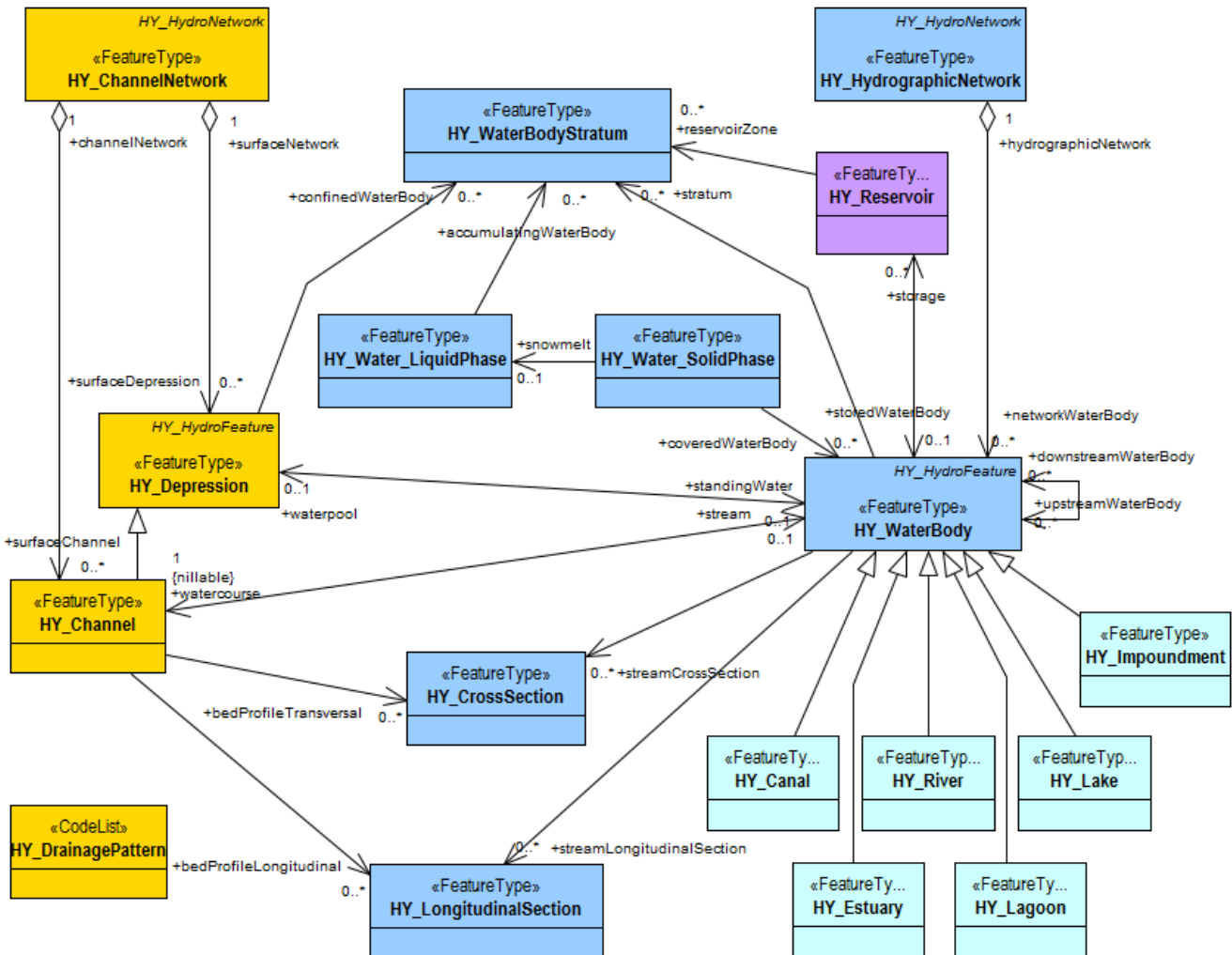


Figure 37. Surface Hydro Feature - Application Schema Diagram

The Surface Hydro Feature model (Figure 37) conceptualizes the accumulation of water on the land surface in waterbodies (shown in Blue), each made unique by its origin, size, or movement. With respect to the management and storage of water resources, a concept of water storage is provided and allows any waterbody type to be considered a managed reservoir (shown in Purple).

Relying on a conceptual separation of waterbody and container, the Surface Hydro Feature schema defines a network of potentially connected depressions and channels on the land surface which periodically or continuously contain water (shown in Orange). Separate from the hydrographic network of permanent or temporary waterbodies, the channel network can be used as the connecting system.

The definitions in this schema are rooted in the definitions given in the WMO/UNESCO Glossary of

Hydrology which defines a network of watercourse regardless of the location in respect to the Earth's surface. The conceptual model defined here has been vetted in the context of surface water hydrology. In other words, in this standard, 'channel network' and 'hydrographic network' refer to surface channels or other containers for surface-waterbodies.

The Surface Hydro Feature application schema contains the leaf packages: Channel Network, Hydrographic Network, Water Body Types and Storage. [Figure 38](#) shows the external and internal dependencies.

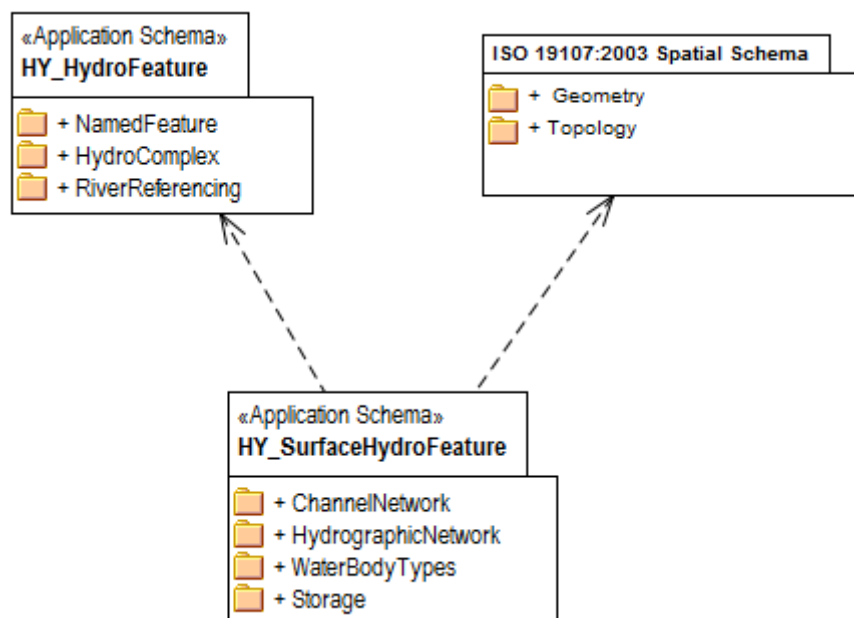


Figure 38. Surface Hydro Feature - dependencies

7.4.1. The Channel Network model

The Channel Network model defines a network of connected depressions and channels which, in its entirety, can realize a catchment ([Figure 39](#)). Usually this is a network of linear flowpaths realizing catchments connected to each other within the containing catchment realized by the entire network. This allows representation of the drainage pattern even if logically connected features may or may not be connected in the context of a particular representation.

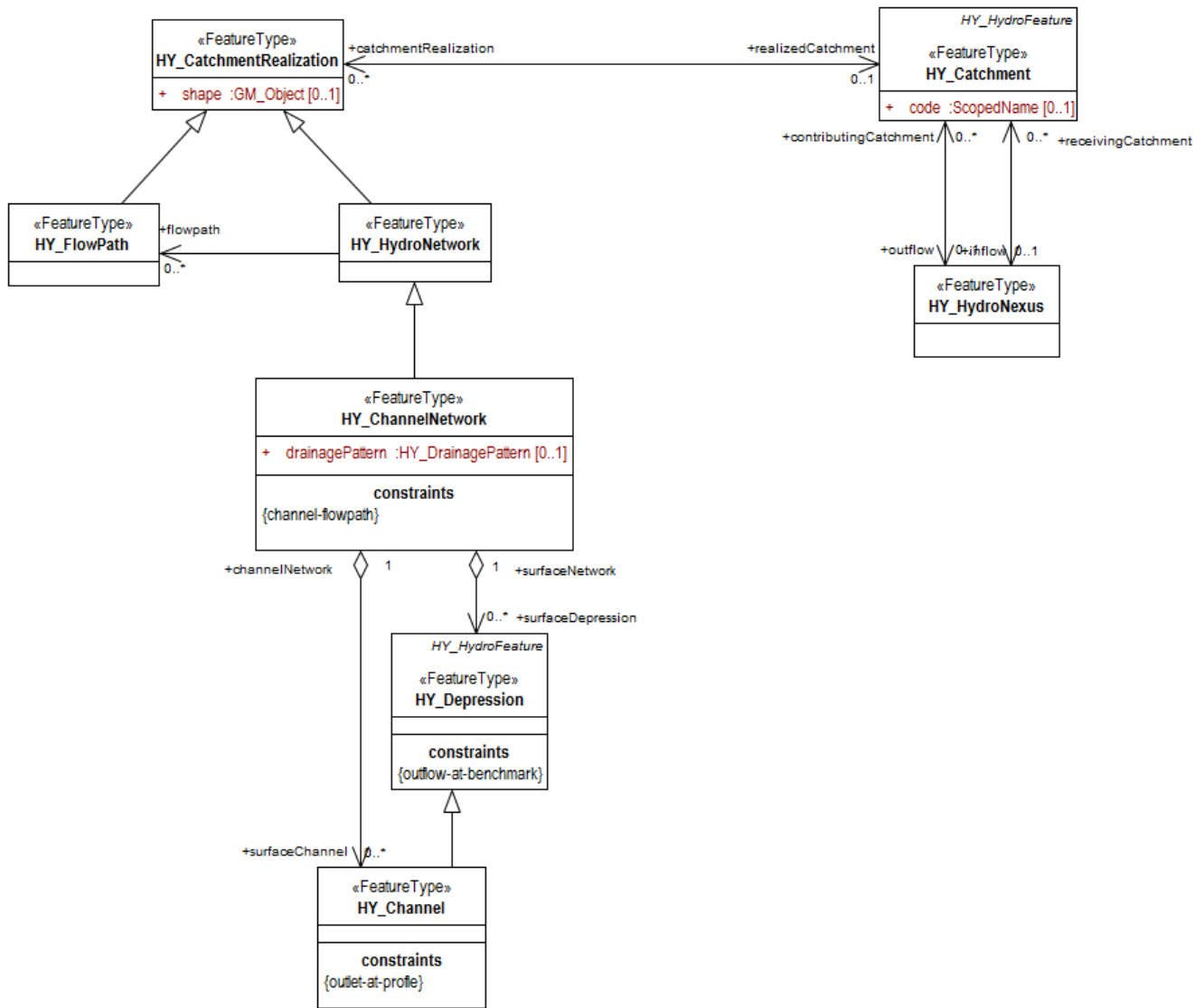


Figure 39. Channel Network realizing the catchment (UML class diagram)

The channel network is defined independent of the hydrographic network. This separates the concerns of hydraulics, focused on the analysis and design of channels and conduits, from the concerns of hydrology, focused on the occurrence and movement of water over land and in waterbodies. It allows a catchment to be realized as a network of connected channels and depressions, regardless of whether or not water is contained in them.

A single depression or channel may realize the catchment, either as part of the network (Figure 39) or via a reference feature which realizes the conceptual hydro nexus of the catchment (Figure 40). For example, a point at an associated cross or longitudinal section may be considered to realize the outflow of the catchment which is realized by the channel expressed as a flowpath.

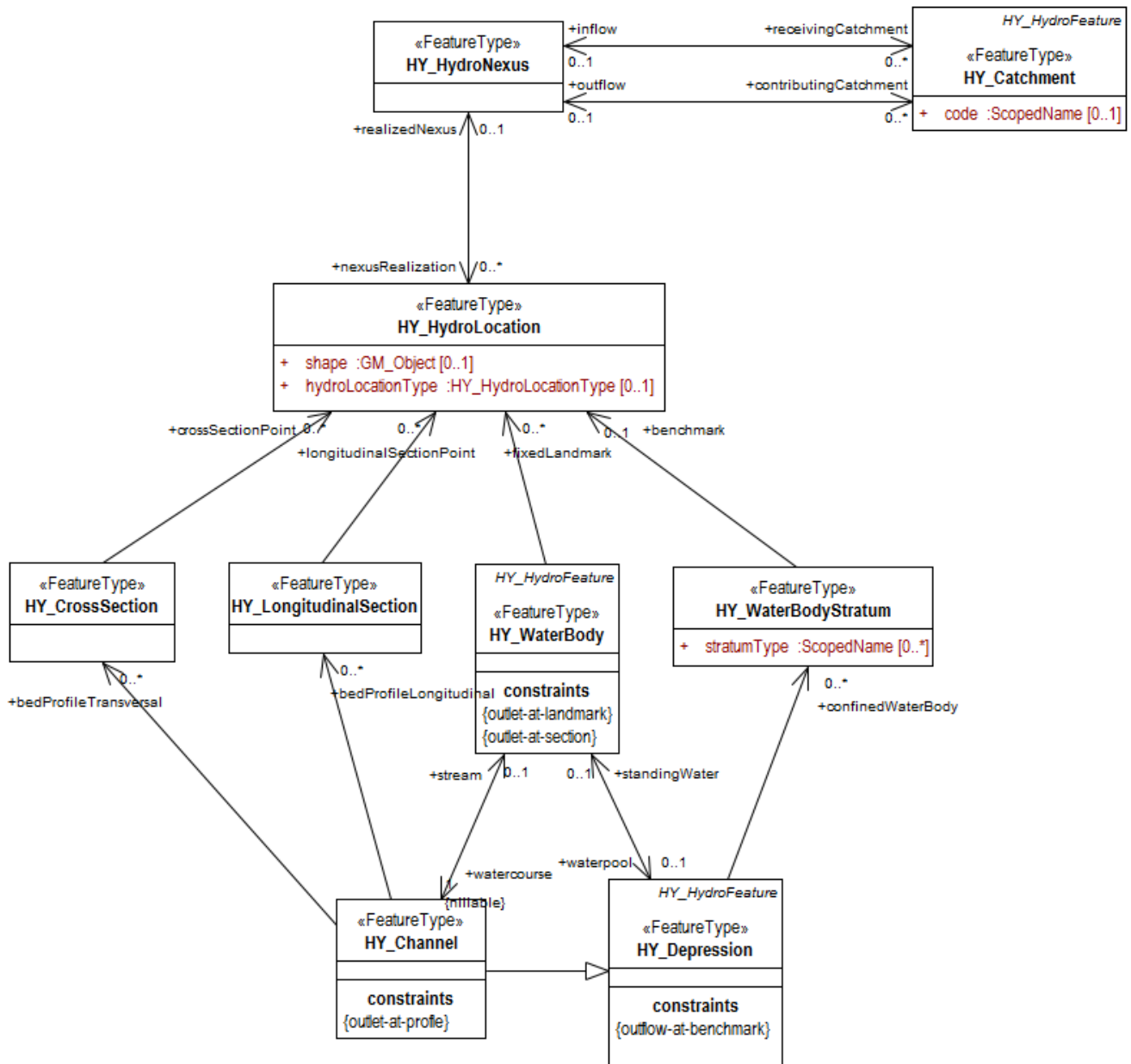


Figure 40. Depression and Channel realizing the hydro nexus (UML class diagram)

Channel Network

The HY_ChannelNetwork feature type specializes the HY_HydroNetwork realization defined in the Hydro Feature core model, specifically as an aggregate of surface depressions and surface channels which continuously or periodically contain water, without imposing a particular drainage pattern. This allows representation of the network, even if logically connected features are not connected at the representation level. If the realized catchment is connected with other catchments via hydro nexuses, the channel network is considered connected to the channel network realizing these catchments.

HY_ChannelNetwork has *surfaceDepression* and *surfaceChannel* associations, and carries a *drainagePattern* attribute; it inherits through generalization the *shape* attribute, the *realizedCatchment* association as well as *flowpath*, *catchmentDivide* and *catchmentArea* associations. Depending on the application, the channel network and the related features may be described by suitable attributes. A *channel-flowpath* constraint is defined to support the recognition of the channel as flowpath realizing the catchment.

Table 16. *HY_ChannelNetwork*

Property	Concept or definition	Relation
<i>drainagePattern</i>	drainage pattern. An implementation may use a term from the HY_DrainagePattern code list. Note that alternative code lists may be used but should be related to the terms in Annex B.3 using an appropriate formalism.	Attribute
<i>surfaceDepression</i>	depression on the land surface which realizes the catchment either separately, or as part of the channel network.	Association
<i>surfaceChannel</i>	channel on the land surface which realizes the catchment either separately, or as part of the channel network.	Association
<i>channel-flowpath</i>	defines that whenever a flowpath exists as part of a network, the surface depression and surface channel should be recognized as a flowpath. Geometrically represented as a curve, channel-flowpath will support to 'measure' a position on, or along, the channel using its centreline as shape.	Constraint

Depression

The HY_Depression feature type specializes the general HY_HydroFeature class. It describes land lower than the surrounding land as a container for standing water. A depression is part of the network of channels and depressions forming the connecting system in which waterbodies are contained as parts of a hydrographic network. Through generalization, HY_Depression inherits the *name* property. It has associations for the *surfaceNetwork* in which it participates, a body of *standingWater* and a stratum of a *confinedWaterBody*. An *outlet-at-benchmark* constraint emphasizes that a benchmark on the confined waterbody at the outlet of the catchment that is realized by the channel network.

Table 17. *HY_Depression*

Property	Concept or definition	Relation
<i>surfaceNetwork</i>	network of surface channels and depressions, the depression is part of.	Association
<i>standingWater</i>	identifies the body of stagnant water contained in the depression.	Association
<i>confinedWaterBody</i>	identifies a stratum of waterbody contained in the depression.	Association

<i>outlet-at-benchmark</i>	defines that a benchmark hydro location which realizes a hydro nexus, should be recognized as the outflow of the contributing catchment realized by the surface network that the depression is part of.	Constraint
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Channel

The HY_Channel feature type specializes the HY_Depression class with respect to a natural or man-made, open or closed channel through or along which water may or may not flow. A channel is part of the network of channels and depressions which forms the connecting system for the hydrographic network; a channel may have vertical sections at right angles to the main (average) direction of flow or along its centerline.

HY_Channel has an association indicating the *channelNetwork* in which it participates. It carries the associations: *stream*, *bedProfileTransversal* and *bedProfileLongitudinal*. HY_Channel inherits from generalization the *confinedWaterBody* association and the *outflow-at-benchmark* constraint. An *outlet-at-profile* constraint emphasizes the recognition of vertical section as the outlet of the catchment that is realized by the channel network.

Table 18. HY_Channel

Property	Concept or definition	Relation
<i>channelNetwork</i>	network of surface channels and depressions, the channel is part of.	Association
<i>stream</i>	identifies the waterbody periodically or continuously flowing in the channel, including subterranean streams.	Association
<i>bedProfileTransversal</i> and <i>bedProfileLongitudinal</i>	identifies a transversal or longitudinal vertical shape of a channel, carrying a permanent reference location which realizes the hydro nexus of the catchment which is realized by the channel.	Association
<i>outlet-at-profile</i>	defines that a location at a vertical section of a channel which realizes a hydro nexus, should be recognized as outflow of the contributing catchment realized by the surface network the channel is part of.	Constraint

7.4.2. The Hydrographic Network model

The Hydrographic Network model defines a logical network of waterbodies which, in its entirety, realizes a catchment (Figure 41). Most typically, this is as a network of linear flowpaths realizing catchments connected to each other within a containing catchment that is realized by the entire network. This allows representation of the network of 'blue lines', even if logically connected features are not connected at the representation level.

The hydrographic network is defined independent of the channel network. This maintains a conceptual separation of concerns of hydrology studying the occurrence, accumulation, and circulation of water and studies related to containers of waterbodies. It allows realization of the catchment as a network of moving or standing waterbodies, regardless of the channels and depressions.

A single waterbody can realize its catchment either as part of the hydrographic network (Figure 41), or via a reference location which realizes the hydro nexus of the catchment realized by the waterbody (Figure 42). For example, a fixed landmark, or a point at an associated cross section is considered to realize the outflow of the catchment which is realized by the waterbody.

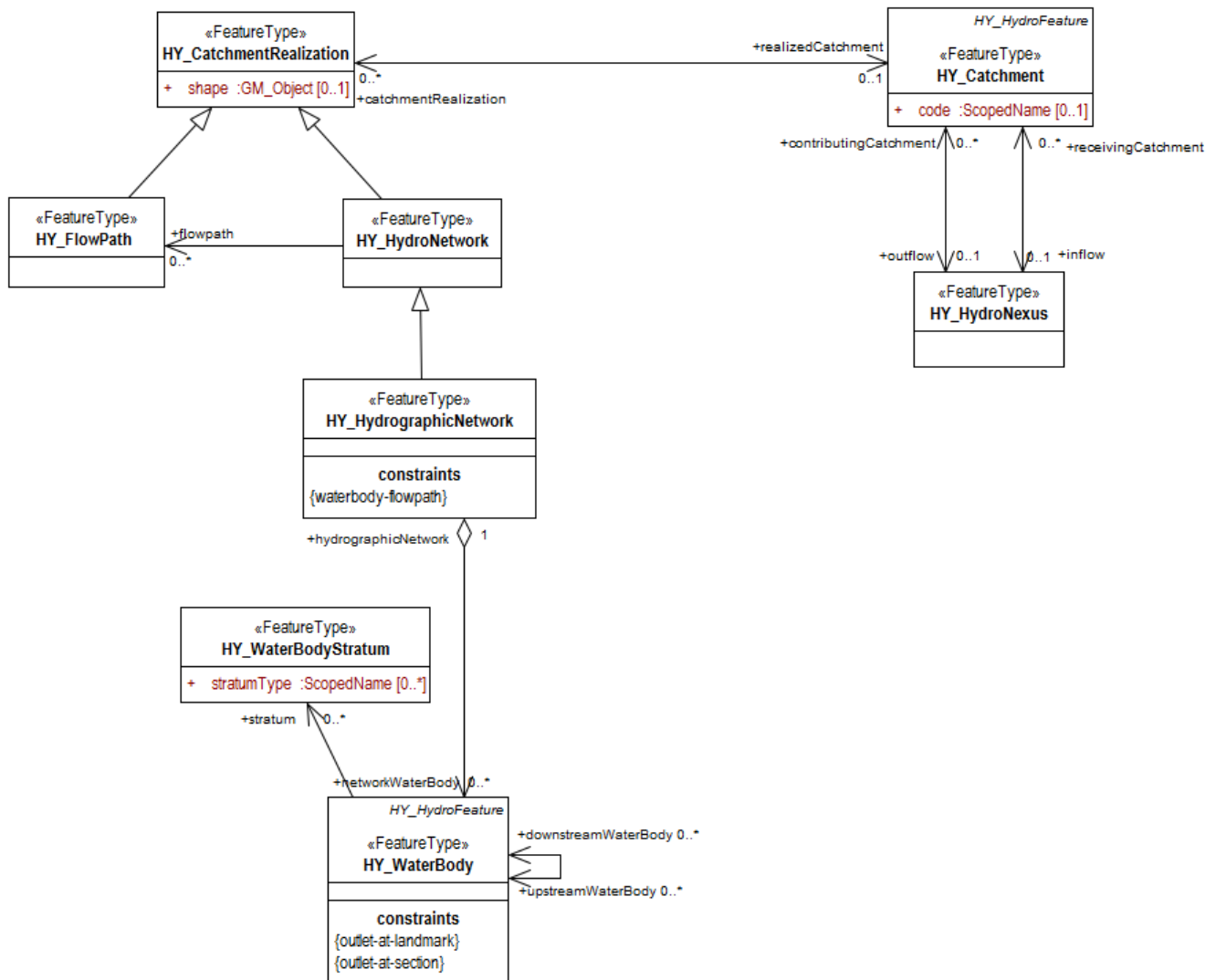


Figure 41. Hydrographic Network realizing the catchment (UML class diagram)

Hydrographic Network

The HY_HydrographicNetwork feature type specializes the HY_HydroNetwork realization defined in the Hydro Feature core model, specifically as an aggregate of permanent or temporary bodies of water standing in depressions or moving in channels. If the realized catchment is connected with other catchments via hydro nexuses, the hydrographic network is considered connected to the network realizing these catchments. This allows representation of the network, even if logically connected features are not connected at the representation level. If required, an application focused on surface-waterbodies contained in channels or depressions may use the defined

relationships to describe the realization of a catchment by the hydrographic network, or network parts associated with the channel network.

HY_HydrographicNetwork has a *networkWaterBody* association. Through generalization, it inherits the *shape* attribute and the *realizedCatchment* association as well as *flowpath*, *catchmentDivide* and *catchmentArea* associations. A *waterbody-flowpath* constraint supports the recognition of the waterbody as a flowpath realizing the catchment.

Table 19. HY_HydrographicNetwork

Property	Concept or definition	Relation
<i>networkWaterBody</i>	waterbody which realizes the catchment either separately, or as part of the hydrographic network.	Association
<i>waterbody-flowpath</i>	defines that whenever a flowpath exists as part of a network, the waterbody should be recognized as a flowpath. Geometrically represented as a curve, waterbody-flowpath will support to 'measure' a position on, or along, the waterbody using a centreline as shape.	Constraint

Water Body

The HY_WaterBody feature type specializes the general HY_HydroFeature class. A waterbody is part of the hydrographic network and is either standing in a depression or flowing in a channel, which are parts of the channel network. A waterbody may be segmented in vertical sections at right angles to the main (average) direction of flow or along its centerline, and horizontal strata. Conceptually, each waterbody, or a stratum, could be thought of as a reservoir used for storage, regulation or control of water recourses.

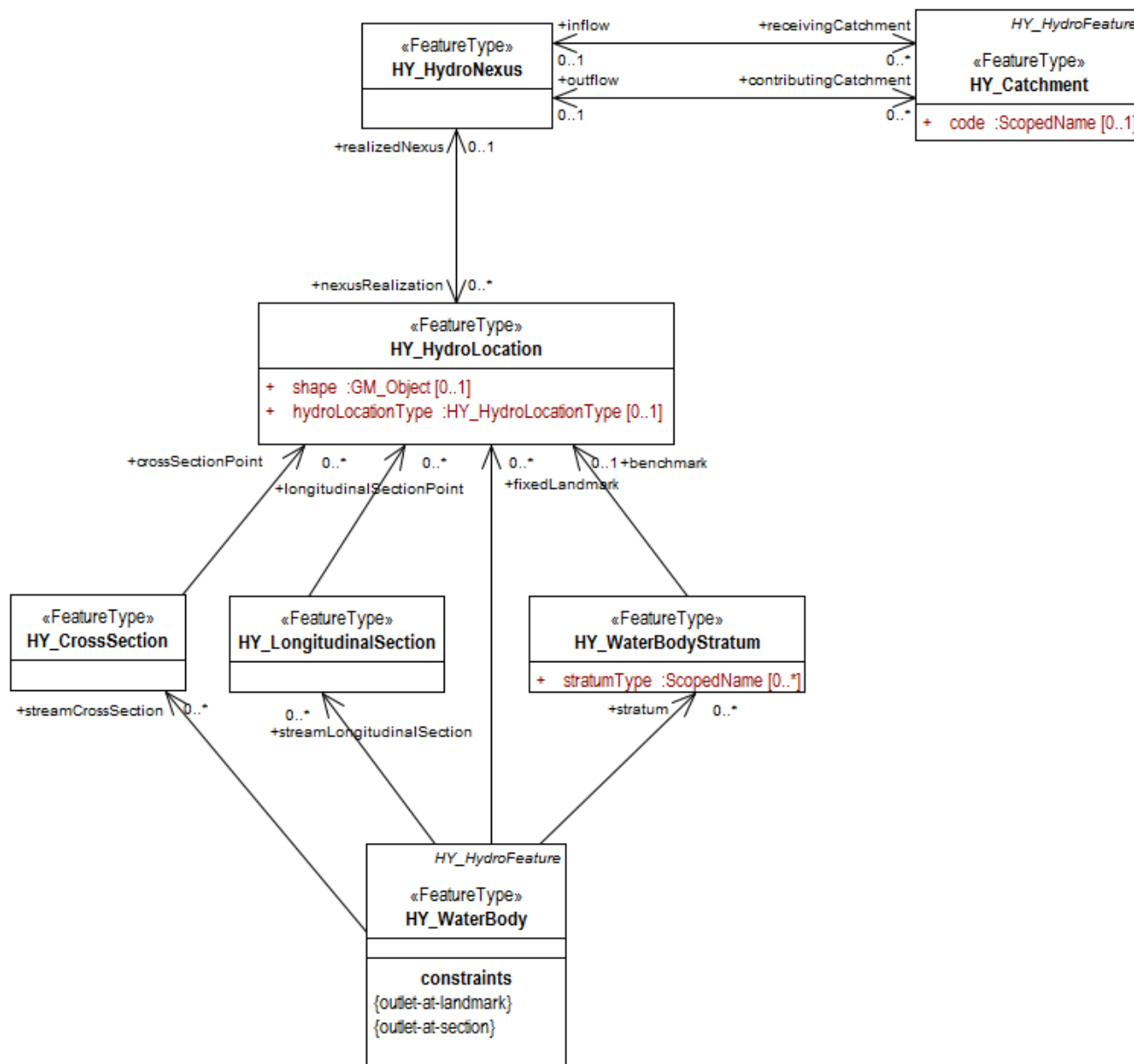


Figure 42. Water Body realizing the hydro nexus (UML class diagram)

Through generalization, HY_WaterBody inherits the *name* property. It has associations for the *hydrographicNetwork* in which it participates, the containing *waterpool* and *watercourse*, the vertical *streamCrossSection*, *streamLongitudinalSection*, a horizontal *stratum*, and a reservoir for storage of water. *Outlet-at-section* and *outlet-at-landmark* constraints emphasize the recognition of a fixed landmark as outlet of the catchment realized by hydrographic network.

Table 20. HY_WaterBody

Property	Concept or definition	Relation
<i>waterpool</i>	identifies the natural or artificial depression which contains standing water, including large interstices in the ground, such as cave, cavern or a group of these.	Association

<i>watercourse</i>	identifies the natural or man-made channel which continuously or periodically contains moving water, including large interstices in the ground, such as cave, cavern or a group of these.	Association
<i>stratum</i>	identifies a horizontal layer of consistent characteristics, or a storage zone of a reservoir.	Association
<i>upstreamWaterBody</i> and <i>downstreamWaterBody</i>	identifies another waterbody immediately upstream or downstream, allowing network navigation without knowing an inflow or outflow of the catchment realized by the waterbody.	Association
<i>fixedLandmark</i>	identifies a fixed landmark as the permanent reference location which realizes a hydro nexus of the catchment realized by the waterbody.	Association
<i>streamCrossSection</i> and <i>streamLongitudinalSection</i>	identifies a vertical section either at right angles to the main (average) direction of flow, or along a centerline.	Association
<i>storage</i>	identifies a reservoir storing water as a resource for future use. This may be used to describe storage characteristics of the waterbody participating in the hydrographic network.	Association
<i>outlet-at-landmark</i>	defines that a fixed landmark on a waterbody should be recognized as the outflow nexus location of the contributing catchment realized by the hydrographic network the waterbody is part of.	Constraint
<i>outlet-at-section</i>	defines that a location at a vertical section of a waterbody should be recognized as the outflow nexus of the contributing catchment realized by the hydrographic network the waterbody is part of.	Constraint

Water-Body Stratum

The HY_WaterBodyStratum feature type describes a horizontal layer in a stratified waterbody determined by differences in thermal or salinity characteristics or by oxygen or nutrient content, or by virtual storage zones of a reservoir. HY_WaterBodyStratum carries the properties: *stratumType* and *benchmark*.

Table 21. HY_WaterBodyStratum

Property	Concept or definition	Relation
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<i>stratumType</i>	characterizes the stratum using a term from a controlled vocabulary. An implementation may use the ScopedName type described in ISO 19103: Conceptual Schema.	Attribute
<i>benchmark</i>	identifies a benchmark which realizes the conceptual hydro nexus of the catchment realized by the waterbody.	Association

Cross-Section and Longitudinal Section

The HY_CrossSection and HY_LongitudinalSection feature types conceptualize the segmentation of a waterbody or a containing channel through vertical sections. Taking into account the conceptual separation of a watercourse, the cross section concept refers to both the cross section of a waterbody orthogonal to the direction of flow, and to the transversal bed profile of a channel. The longitudinal section concept refers to both the vertical section of a waterbody along its centerline, and to the longitudinal bed profile of a channel.

Both types of vertical section associate *crossSectionPoint* and *longitudinalSectionPoint* which should be used to identify a permanent reference location at a vertical section which realizes the conceptual hydro nexus of the catchment realized by the associated channel or waterbody.

Water-LiquidPhase and Water-SolidPhase

The HY_Water_LiquidPhase and HY_Water_SolidPhase feature types provide simple concepts of the accumulation of water in waterbodies. This definition refers to the matter accumulated to a mass of water. In its liquid form water is considered accumulated in waterbodies; in its solid phase water may be accumulated after melting, or as a layer of ice or snow on an open waterbody. The accumulation of water in the atmosphere or below the land surface, e.g. rain, soil moisture or groundwater, is not in scope of this standard, as well as the accumulation of snow and ice in glaciers which is the subject of glaciology science.

Contextually related information models may use the HY_Water_LiquidPhase and HY_Water_SolidPhase feature types to build relationships to an accumulating waterbody, and ultimately to the catchment realized either by the waterbody or by the network of which the waterbody is part.

HY_Water_LiquidPhase has an association with the *accumulatingWaterBody*; HY_Water_SolidPhase has associations with the water from *snowmelt* and *coveredWaterBody*. These associations may be used to identify the waterbody (as part of the hydrographic network) where liquid water is accumulated.

7.4.3. The Surface-Water Body types

The Surface Water model defines typical specializations of a waterbody on the land surface. Being a specialization of the HY_WaterBody class each subtype inherits the *stratum*, *waterpool*, *watercourse*, *upstreamWaterBody*, *downstreamWaterBody*, *fixedLandmark*, *streamCrossSection* and *streamLongitudinalSection* properties. From the general HY_HydroFeature class specialized

waterbodies inherit the *name* property, which allows the handling of names given to them in cross-jurisdiction and multi-lingual contexts. Each specialization is understood to be part of the hydrographic network. There may be other contexts with other specializations, or where a particular segmentation exists, that does not conform to the types defined in this standard.

The HY_River feature type defines the existence of a body of surface water, participating in a hydrographic network, which is special due to its property to permanently or temporarily flow.

The HY_Canal feature type defines the existence of a body of surface water, participating in a hydrographic network, that is special due to its artificial origin (man-made).

The HY_Lake feature type defines the existence of a body of surface water, participating in a hydrographic network, made special due to its considerable size.

The HY_Impoundment feature type defines the existence of a body of surface water, participating in a hydrographic network, seen as being special due to being formed by collecting water, for example in the case of a dam.

The HY_Lagoon feature type defines the existence of a body of surface water, participating in a hydrographic network, which is special due to its shallow depth and interaction with the open sea.

The HY_Estuary feature type defines the existence of a body of surface water, participating in a hydrographic network, made special due to branching and its interaction with the open sea.

7.4.4. The Storage model

The Storage model ([Figure 43](#)) provides a concept to describe any waterbody, in terms of a reservoir storing water for future use. The separation of the storage model allows for description of the hydrographic network without the details of storage capacities that a waterbody may have, and conversely, storage reservoirs can also be described independent of their role within the hydrographic network.

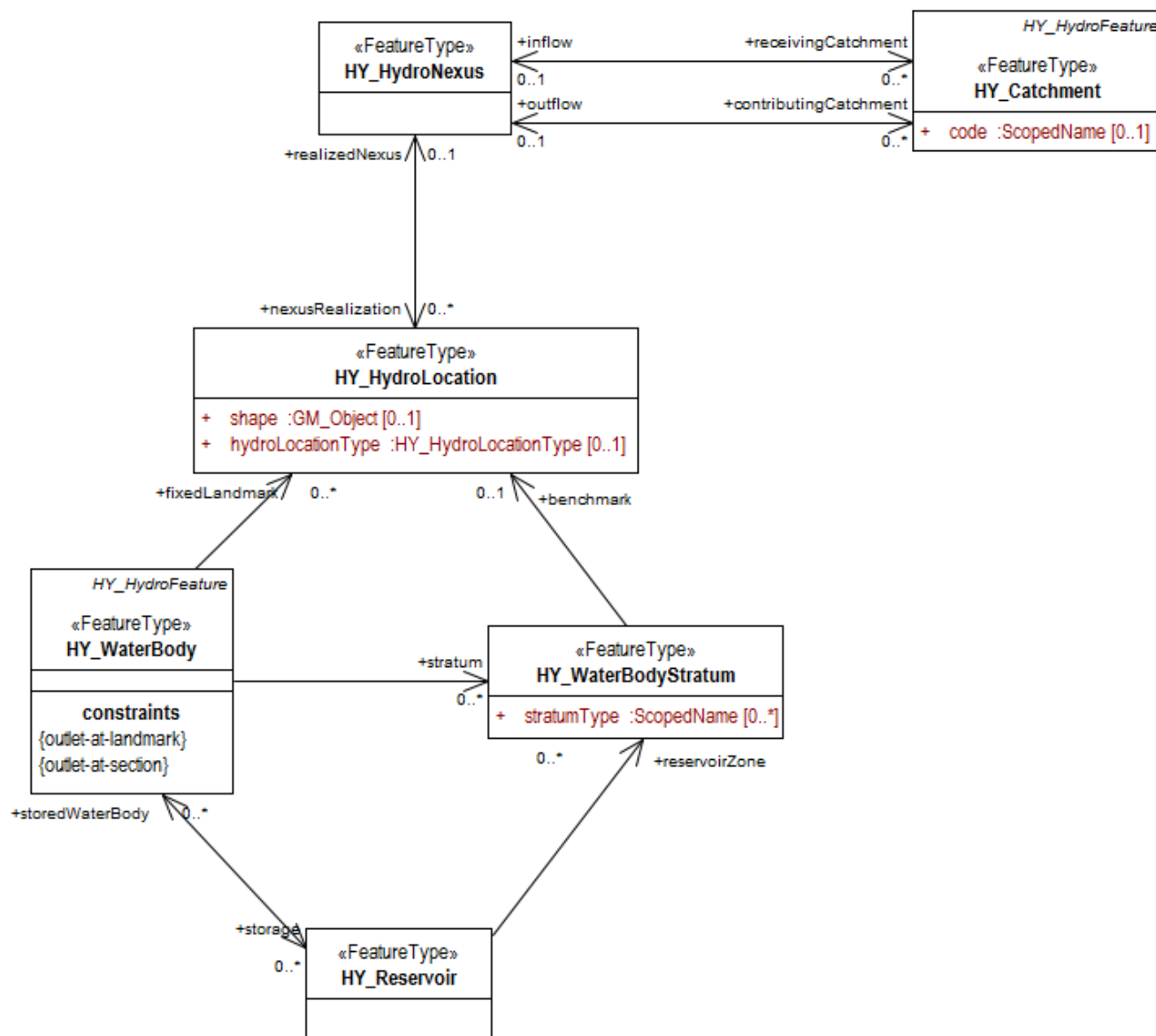


Figure 43. Reservoir realizing the hydro nexus (UML class diagram)

The HY_Reservoir feature type describes the waterbody, either natural or man-made, used for storage, regulation and control of water resources. The reservoir concept refers to a volume of water managed in zones between operating levels. HY_Reservoir has associations between a reservoir and the *storedWaterBody* and a *reservoirZone*.

Table 22. HY_Reservoir

Property	Concept or definition	Relation
<i>storedWaterBody</i>	identifies the network waterbody that specifies the connectivity of the storage reservoir in the hydrographic network.	Association
<i>reservoirZone</i>	identifies the waterbody stratum used for storage, for example a management zone, or flood control zone.	Association

7.5. Hydrometric Network concepts

The Hydrometric Network application schema (Figure 44 and Figure 45) define a logical model to take into account a network of hydrometric stations as a specific realization of the catchment in the perspective of hydrologic observation, without the detail of an observation strategy.

The Hydrometric Network model specifies the concepts defined in the Hydro Feature core model. The general concept is that of a network of logically connected hydrometric stations realizing as a whole the catchment. This enables contextually related information models to relate monitoring stations and observing posts to hydrologic features, as is often required for environmental reporting or when interpreting, analyzing and processing observation results.

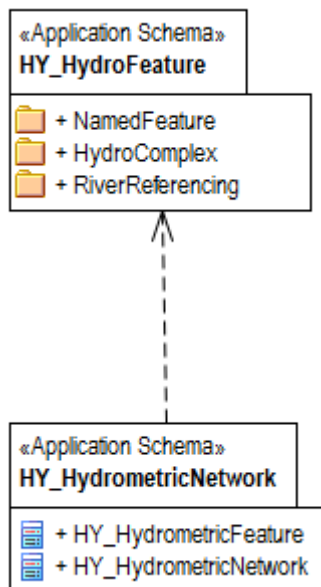


Figure 44. Hydrometric Network - dependencies

The hydrometric network model introduces the concept of a 'position on river' which allows a hydrologic station, which may not have a precisely known location, to be located on a river. This supports the establishment of upstream-downstream relationships between hydrometric features, assignment of a position relative to a 'fixed' hydro nexus, or to place other features of interest relative to the hydrometric station.

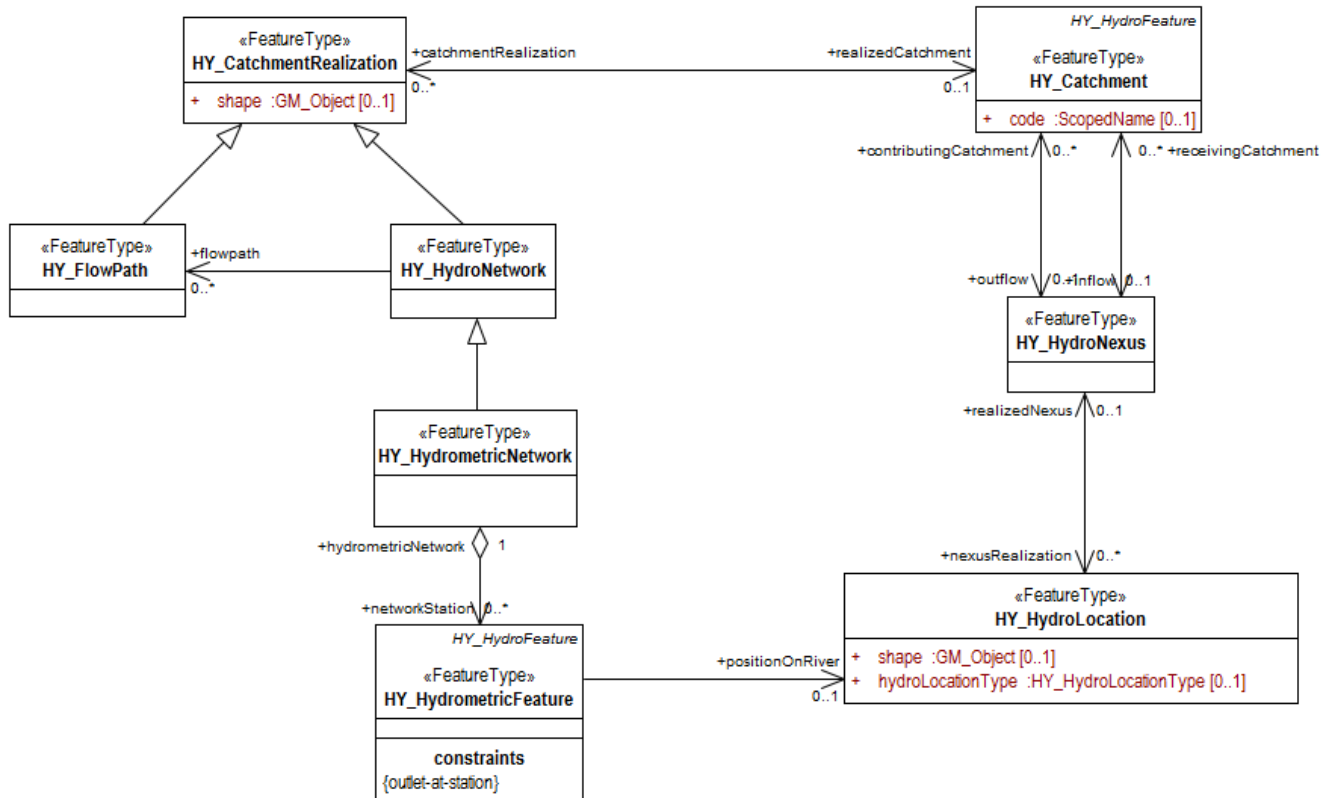


Figure 45. Hydrometric network and hydrometric feature realizing a catchment (UML class diagram)

7.5.1. Hydrometric Network model

The HY_HydrometricNetwork feature type specializes the HY_HydroNetwork realization specifically as an aggregate of hydrometric features. HY_HydrometricNetwork has a *networkStation* association, and inherits through generalization the *shape* attribute, the *realizedCatchment*, *flowpath*, *catchmentDivide* and *catchmentArea* associations.

Table 23. HY_HydrometricNetwork

Property	Concept or definition	Relation
<i>networkStation</i>	hydrometric feature which realizes the catchment either separately, or as part of the hydrometric network.	Association

7.5.2. Hydrometric Feature model

The HY_HydrometricFeature feature type provides a concept of a monitoring station at which data on water are obtained and that realizes the catchment either separately or as part of a hydrometric network (Figure 45). HY_HydrometricFeature has associations for the *hydrometricNetwork* in which it participates, and a *positionOnRiver*. An *outlet-at-station* constraint emphasizes the recognition of a monitoring station as the outlet of the catchment that is realized by the hydrometric network.

Table 24. HY_HydrometricFeature

Property	Concept or definition	Relation

<i>positionOnRiver</i>	<p>identifies the position of the hydrometric feature in the hydrographic network as a hydro location which realizes the hydro nexus of the catchment corresponding to the hydrometric feature.</p> <p>identifies a fixed landmark which realizes the hydro nexus of the catchment realized by the waterbody as a permanent reference location.</p>	Association
<i>outlet-at-station</i>	defines that a monitoring station should be recognized as the outflow of the contributing catchment realized by the hydrometric network the station is part of.	Constraint

Annex A: Conformance Class Abstract Test Suite (Normative)

A.1. Introduction

These test suites verify the compliance of the conformance targets for the HY_Features conceptual model with the HY_Features specification. Each instance of hydrologic feature data is encoded according to a specific implementation schema, so conformance of a schema or a mapping to/from such a schema with the abstract specification is defined as a clear derivation of schema or mapping entities from the concepts, definitions, and constraints of HY_Features.

A.2. Conformance class: HY_Features implementation schema equivalence

Conformance Class	/conf/hy_features_conceptual_model
Requirements Class	/req/hy_features_conceptual_model
Test	/conf/hy_features_conceptual_model/mapping
Requirement	An implementation schema conforming to HY_Features SHALL implement one or more feature types defined by the HY_Features UML model in this standard, including all mandatory properties, associations, and default values. A mapping implementation conforming to HY_Features SHALL implement mappings between existing feature types and one or more HY_Features feature types as defined in the HY_Features UML model in this standard, including all mandatory properties, associations, and default values.
Test purpose	All relevant elements of an implementation schema or data exchange mapping including hydrologic features are valid implementations of HY_Features concepts, associations, and constraints.
Test method	Inspect the correspondence between implementation schema or data exchange mapping elements and the HY_Features model to determine that all relevant elements are mapped to HY_Features concepts, associations, and constraints.
Test type	Inspection
Test	/req/hy_features_conceptual_model/GF_Feature
Requirement	Each implemented HY_Features feature type SHALL be an instance of the GF_FeatureType (aka FeatureType) «metaclass»
Test purpose	All relevant elements of an implementation schema or data exchange mapping including hydrologic features are also valid instances of the GF_FeatureType «metaclass».

Conformance Class	/conf/hy_features_conceptual_model
Test method	Inspect the definitions of relevant schema or mapping elements to determine that defined features are valid instances of the GF_FeatureType «metaclass»..
Test type	Inspection

Annex B: Code lists for the HY_Features model

B.1. Terms identifying a location determined to realize conceptual hydro nexus

Code list	Realized Nexus Type
barrage	barrier across a stream provided with a series of gates or other control mechanisms to control the water-surface level upstream, to regulate the flow or to divert water supplies into a canal.
bifurcation	division of a stream into two branches.
catchment outlet	common outlet for the runoff drained by the catchment.
confluence	joining, or the place of junction, of two or more streams.
dam	barrier constructed across a valley for impounding water or creating a reservoir.
diversion of water	transfer of water from one watercourse to another, such watercourses being either natural or man-made.
extraction well	shaft or hole sunk, dug or drilled into the earth to extract water.
fork	(1) place where two or more streams flow together to form a larger stream. (2) place where a stream divides into two or more streams.
hydrometric station	station at which data on water in rivers, lakes or reservoirs are obtained on one or more of the following elements: stage, streamflow, sediment transport and deposition, water temperature and other physical properties of water, characteristics of ice cover and chemical properties of water.
infiltration well	recharge well that is sunk only into the unsaturated zone distinguished from an injection well.
inlet structure	structure admitting water supplies from the source or through an intake structure built upstream.
intake	structure or site, the purpose of which is to control, regulate, divert, and admit water directly from the source, through an inlet built upstream.
outlet structure	opening (structure) through which water flows out or is extracted from a reservoir or stream.
ponor	hole or opening in the bottom or side of a depression where a surface stream or lake flows either partially or completely underground into a karst groundwater system.
pour point	specified catchment outlet defined to delineate a catchment upslope from that point.
rapids	reach of a stream where the flow is very swift and shooting, and where the surface is usually broken by obstructions, but has no actual waterfall or cascade.

reference climatological station	climatological station the data of which are intended for the purpose of determining climatic trends. This requires long periods (not less than thirty years) of homogeneous records, where man-made environmental changes have been and/or are expected to remain at a minimum. Ideally the records should be of sufficient length to enable the identification of secular changes of climate.
river mouth	place of discharge of a river into a sea or a lake.
sinkhole	place where water disappears underground in a limestone region. It generally implies water loss in a closed depression or blind valley.
source	origin of river.
spring	place where water flows naturally from a rock or soil onto land or into a body of surface water.
waterfall	vertical fall or the very steep descent of a stream of water.
weir	overflow structure which may be used for controlling upstream water level or for measuring discharge or for both.

B.2. Terms commonly used in hydrology to describe a spatial relation between two locations

Code list	Distance Description
at	located at the (reference) location.
between	located between two (reference) locations.
downstream	located downstream of the (reference) location, e.g. in the direction of the current in a river or stream.
left	located left-hand of the (reference) location when facing downstream.
nearby	located a short distance from the (reference) location.
right	located right-hand of the (reference) location when facing downstream.
upstream	located upstream of the (reference) location, e.g. in the direction towards the source of a stream.

B.3. Terms commonly used in hydrology to describe a drainage pattern

Code list	Drainage Pattern
annular	main rivers that have a circular pattern with subsidiary channels at right angles.
centripetal	streams that flow inward to center.
dendritic	spreading treelike arrangement (when viewed in an upstream direction) converging into a single outlet downstream; no evident orientation of channels (random orientation).

distributary	one main channel divides into many channel-ways ending with many outlets.
parallel	main channels regularly spaced and parallel or sub-parallel to each other; tributaries join at very acute angles.
pinnate	featherlike, closely grouped , short tributaries (fine texture).
radial	streams flow outward from center.
rectangular	drainage forms a perpendicular net with the two directions equally developed.
trellis	a dominant drainage direction with a secondary direction perpendicular to this; primary tributaries join main stream at right angles, secondary tributaries parallel main stem.

B.4. Terms commonly used to indicate the type of name usage.

Code list	Usage Type
conventional	accepted, used, or practiced by most people ('agreed by convention')
historical	restricted to or based on fact in history
official	ordered or allowed by those in authority
vernacular	used in or suitable for speech, usually not used in formal writing

Annex C: HY_Features - AHGF Mapping

This is a descriptive mapping for the Australian Hydrological Geospatial Fabric (AHGF) [11]. It is intended to provide an understanding of the basic relationship of HY_Features concepts and the AHGF hydrologic feature implementation.

C.1. Catchment Model

HY_Features Name	AHGF Name/Class	Comment
HY_Catchment	ContractedCatchment 'Base-level' Catchment	<p>A contracted catchment is a catchment identified via ConCatID, which conceptualizes a holistic unit of hydrology draining to a common outflow (HY_HydroNexus) with a known identity to which a persistent identifier is assigned (ConNodeID). This logical catchment may also have a single inflow, which together with the outflow, define a FlowPath for the catchment and take part in the AHGF topology tables (AHGFNodeLinkConnectivityDown and AHGFNodeLinkConnectivityUp). A catchment may have multiple hydrologic-realizations and is therefore not restricted to the single geometric representation given by AHGFContractedCatchment.</p> <p>Additionally, AHGF 'base-level' catchments, from which contracted catchments are derived, can be seen as a second set of conceptualized units of hydrology draining to a single common outflow and with a single inflow. These catchments are given a non-persistent identifier (HydroID) and like contracted catchments, their flow paths take part in AHGF topology tables (AHGFNetworkConnectivityDown and AHGFNetworkConnectivityUp). The polygon geometric representation of these catchments is provided by AHGFCatchment.</p>
HY_DendriticCatchment	ContractedCatchment	All contracted catchment features are constrained to be dendritic in the AHGF. A contracted catchment's outflow can only be received by a single downstream contracted catchment.
HY_InteriorCatchment	ContractedCatchment Subset of 'Base-level' Catchment	<p>Contracted catchments that normally do not contribute flow to a neighboring contracted catchment or to the coast (i.e. catchments with potential connections to groundwater or atmospheric systems).</p> <p>'Base-level' catchments that normally do not contribute flow to a neighboring base-level catchment or to the coast. These catchments have no realized FlowPath or HydroNexus.</p>

HY_CatchmentAggregate	Collections of Contracted Catchments Collections of 'Base-level' Catchments	<p>Sets of non-overlapping dendritic and interior contracted catchment features aggregated into larger encompassing catchments. Such aggregations are a fundamental concept in the AHGF and a primary reason for the creation of the contracted catchments. The AHGF Topographic Drainage Divisions (AWRADrainageDivision) and River Regions (RiverRegions) are examples of such aggregations.</p> <p>Contracted catchments, derived from collections of 'base-level' catchments, can themselves be seen as further examples of a catchment aggregate.</p>
HY_HydroNexus	Subset of Contracted Nodes	A hydrologic significant entity conceptualizing the outflow of a contracted catchment. All contracted nodes in the AHGF are determined by a set of defined business rules and assigned with persistent identifiers (ConNodeID). A subset of these contracted nodes act in the role of outflow node (ConNodeID) for one or more contracted catchment(s) and can also act as an inflow node (FConNodeID) for zero or one contracted catchment.
HY_HydroLocation	AHGFNode AHGFNetworkNode	<p>Features in AHGFNode are the subset of contracted nodes, which realize instances of HY_HydroNexus. All AHGFNode features therefore act in the role of an outflow node (ConNodeID) for a contracted catchment and may also additionally act in the role of inflow node (FConNodeID) for a single contracted catchment. Some examples of contracted nodes that realize hydro nexus in the AHGF are confluences, coastal outlets, reservoir outlets and monitoring point stream gauges. The AHGF also defines a specialization of HY_HydroLocation, whereby a collection of disjoint points can be used to realize a single nexus, effectively forming a 'diffused' outflow (or inflow) for a contracted catchment. Instances of such specialized hydro locations, which are used for simplification of complex drainage patterns at the boundary of contracted catchment, will always realize one contracted node. This representative node is the node used for topological realization of the hydro nexus.</p> <p>All AHGFNetworkNode features are further examples of hydro locations in the AHGF.</p>

HY_CatchmentRealization	Feature identified by ConCatID	<p>Any feature, collection of features or topological data identified by a single ConCatID (contracted catchment). Single instances of AHGFContractedCatchment and AHGFLink as well as collections of AHGFNetworkStream, AHGFNetworkNode, AHGFCatchment (base-level sub-catchments) and AHGFWaterbody features sharing a common ConCatID.</p> <p>Note: features of subtype AHGFContractedCatchment::NoFlowArea in the AHGF are special-case un-realizable contracted catchments (normally small islands) that do not have an associated contracted node (i.e. No HY_HydroNexus).</p> <p>All AHGF 'base-level catchments have at least one catchment realization, being a single instance of AHGFCatchment, and many are also realized by a single AHGFNetworkStream.</p>
HY_CatchmentArea	Not represented	<p>An instance HY_CatchmentArea realizes an instance of HY_Catchment as a catchment area connecting its inflow and outflow and including a plane surface. Although the polygon representing a catchment might be thought of as an area, the subset of a DEM or another land cover dataset would be more in line with the meaning of CatchmentArea as defined by HY_Features.</p> <p>Although not directly represented in the AHGF, the inherent close relationship between the features of AHGFContractedCatchment, AHGFCatchment and the DEM (9 second or 1 second) allow us to postulate a potential realization of a contracted catchment as the area of the DEM bounded by that contracted catchment.</p>
HY_CatchmentDivide	AHGFContractedCatchment AHGFCatchment	<p>The AHGFContractedCatchment polygon feature that realizes a contracted catchment.</p> <p>The AHGFCatchment polygon feature that realizes a base-level catchment.</p>
HY_CartographicRealization	AHGFMappedStream	<p>The features of AHGFMappedStream within the AHGF Surface Cartography product, provide an additional realization of both contracted catchments and base-level catchments. Collections of features from AHGFNetworkStream identified by a single ConCatID, while a realization of a contracted catchment themselves, are also attributed with identifiers that relate them to corresponding mapped stream features.</p>

C.2. Hydrographic Network

HY_Features Name	AHGF Name/Class	Comment
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HY_Hydrographic Network	Subsets of AHGFNetworkStream and AHGFWaterbody	The collection of AHGFNetworkStream flow segment and water area segment features (subtypes: NetworkFlowSegment & NetworkWaterAreaSegment) and on-network AHGFWaterbody features within a particular contracted catchment (identified by a single ConCatID) can be seen to realize that catchment as its hydrographic network.
HY_WaterBody	AHGFNetworkStream (subtypes: NetworkFlowSegment & NetworkWaterAreaSegment) and AHGFWaterbody	AHGFNetworkStream flow segment and water area segment features and AHGFWaterbody features represent water bodies in the AHGF. These features indicate that there is water contained in some channel or other containing feature.
HY_ChannelNetwork	AHGFNetworkStream (subtype: NetworkArtificialFlowSegment)	While a complete channel network is not represented in the AHGF, the subset of artificial flow segment features from AHGFNetworkStream may be seen as being a partial channel network. Importantly, for a particular contracted catchment (identified by a single ConCatID) the collection of artificial flow segment features can be seen to realize that catchment. However, the HY_HydroNetwork realization for a catchment is only complete (i.e. fully connected) when the Hydrographic Network and Channel Network realizations are combined.
HY_Depression	Not represented	
HY_Channel	AHGFNetworkStream (subtype: NetworkArtificialFlowSegment)	The subset of artificial flow segment features from AHGFNetworkStream can be thought of as a partial channel network in that they indicate where water may flow, even though not normally present.
HY_Reservoir	AHGFWaterbody (subtype: Reservoir)	The subset of reservoir features from AHGFWaterbody.
HY_FlowPath	AHGFLink	Each link feature in AHGFLink realizes a contracted catchment identified by a single ConCatID. A link is essentially a straight line linking realizations of contracted nodes representing the inflow and outflow for the contracted catchment. Note: The AHGF currently does not have FlowPath features for contracted catchments in headwater areas.
HY_LongitudinalSection	Not represented	
HY_CrossSection	Not represented	

HY_WaterBodyStratum	Not represented	
HY_Water_LiquidPhase	Not represented	
HY_Water_SolidPhase	Not represented	

C.3. Hydrometric Network

HY_Features Name	AHGF Name/Class	Comment
HY_HydrometricNetwork	AHGFNode (subtype: GhostNode)	In the AHGF, hydrometric features are a subset of AHGFNode features that realize contracted nodes. Thus, single instances or pairs of hydrometric features acting in the roles of inflows and outflows for contracted catchments, could be seen to form a hydrometric network which realizes a single contracted catchment.
HY_HydrometricFeature	AHGFNode (subtype: GhostNode)	<p>Hydrometric features, such as stream gaging stations, are represented as a subset of AHGFNode features.</p> <p>Note: While hydrometric features were included in earlier versions of the AHGF, version 3 products were the first to see them included as realizations of contracted nodes (i.e. to act in the role of inflow and outflow for contracted catchments).</p>
HY_IndirectPosition	Not represented	Measures are not yet explicitly included in the AHGF. Note that monitoring stations are located 'on river' via realizations of contracted nodes (AHGFNode) and thus act in the role of inflow and outflow for contracted catchments.

Annex D: HY_Features - NHDPlus Mapping

This is a descriptive mapping for the USGS National Hydrography Dataset Plus (NHDPlus) [10]. It is intended to provide an understanding of the basic relationship of HY_Features concepts and the NHDPlus hydrologic feature implementation.

D.1. Catchment Model

HY_Features Name	NHDPlus Name	Comment
HY_Catchment	comid catchment	The comid catchment is the feature that takes part in PlusFlow topology table, has associated accumulated characteristics, etc. Could also be the collection of catchments that contribute to a given reachcode reach, HUC watershed outlet, or another identifiable watershed outlet. Not necessarily the catchment polygon features, but more generally, the unit of hydrology represented by catchment polygons and other data keyed to the comid.
HY_DendriticCatchment	comid catchment	NHDPlus catchments not following any diversions in the flow tables
HY_InteriorCatchment	comid catchment	NHDPlus catchments that do not contribute flow.
HY_CatchmentAggregate	collection of comid catchments	Including interior catchments and not following diversions in the flow tables
HY_HydroNexus	fromNode or toNode	NHDPlus nodes are inflow (fromNode) and outflow (toNode) nodes of a given comid catchment.
HY_HydroLocation	fromNode or toNode location, point location of point events, etc.	HY_HydroLocation can be used as a reference location for any point associated with a feature. Typically, this is for hydro nexus locations and monitoring locations, but may be used for many other feature types. The downstream end and upstream end of an NHDPlus flowline would be considered the hydro location of a hydro nexus.
HY_CatchmentRealization	Any entity that is identified by a comid	In NHDPlus, the comid identifies an unrealized catchment. Any geometric or topologic data that is referenced to a comid can be said to realize that catchment. This includes upstream aggregations of the network or catchment areas that form complete watersheds.
HY_CatchmentArea	Not Represented	While the polygon representing a catchment might be thought of as an area, the subset of a DEM or another land cover dataset would be more in line with the meaning of CatchmentArea.
HY_CatchmentDivide	comid catchment polygon	The polygon representing a comid catchment should be thought of as the CatchmentDivide

HY_CartographicRealization	A map of a catchment	The NHDPlus dataset doesn't include any, but if a map view of a catchment is created at any scale, it could be said to be a cartographic realization of a catchment.
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D.2. Hydrographic Network

HY_Features Name	NHDPlus Name	Comment
HY_Hydrographic Network	collection of flowlines and waterbodies	The collection of perennial and ephemeral flowlines as well as so-called double line streams and on-network lakes within any collection of catchments (an HY_Catchment) can be considered its hydrographic network.
HY_WaterBody	Perennial flowlines and waterbodies	Perennial flowlines are thought to represent waterbodies as well as waterbody polygons that represent wide streams and lakes. These features indicate that there is water contained in some channel or other container.
HY_ChannelNetwork	Not represented	
HY_Depression	Not represented	
HY_Channel	Ephemeral flowlines.	While NHD doesn't have an explicit channel concept, ephemeral flowlines can be thought of as a channel in that they indicate that water can flow there, but may not be present in the flowline container at all times.
HY_Reservoir	waterbodies that are reservoirs	Any waterbody that can be categorized as a reservoir in that it is a waterbody that has a management regime.
HY_FlowPath	flowlines and reaches	A flowline (or reach) is a linear representation of the catchment (or collection of catchments associated with a reach) it shares an id with. For NHD Events, the reachcode reach is the flowpath because it is the linear element used for linear referencing.
HY_LongitudinalSection	Not represented	
HY_CrossSection	Not represented	
HY_WaterBodyStratum	Not represented	
HY_Water_LiquidPhase	Not represented	
HY_Water_SolidPhase	Not represented	

D.3. Hydrometric Network

HY_Features Name	NHDPlus Name	Comment
HY_HydrometricNetwork	collection of events	A collection of events that are hydrometric features could be considered a hydrometric network.
HY_HydrometricFeature	event	A hydrometric feature, such as a stream gaging station, is represented as an event.
HY_IndirectPosition	measure	The measure is an indirect position of type relative position because it is a percent.

Annex E: HY_Features-INSPIRE Hydrography Theme

This table assigns core features as defined in the INSPIRE Hydrography theme [2] to HY_Features core concepts. It also indicates relationship between both terms and potential conditions in which they can be associated.

This table should not be understood in terms of a 'conceptual mapping' of clearly defined relationships between two logical concepts, but rather as a simple approach to show compatibility of concepts, based on the meaning expressed in the definitions, and without imposing a particular implementation. Since each dataset that implements the INSPIRE theme will have a different legacy of documentation and information modeling, a conceptual mapping would be expressed differently. Applications implementing the INSPIRE Hydrography theme can use this listing to understand how a particular dataset may relate to the HY_Features concepts.

Note that in INSPIRE a base 'HydroObject' concept has been defined. Many INSPIRE hydrography Features mentioned below are specialization of this one. Thus, they inherit a hydroid attribute which targets the topic of multiple representations of the same object: *'An identifier that is used to identify a hydrographic object in the real world. It provides a 'key' for implicitly associating different representations of the object.'*

E.1. Catchment Model

HY_Features Name	Relationship between concepts	INSPIRE Hydrography Feature Name + potential condition(s)	Definition / Description
HY_Catchment	Is like	DrainageBasin In case that HY_Catchment is realized by HY_CatchmentArea	Area having a common outlet for its surface runoff. NOTE 1 Regarding the different classifications of drainage basins, no distinction is made between drainage basins / sub-basins since this will vary with application. It is possible to build basins from other basins. NOTE 2 The outlet of a drainage basin may be a canal or a lake. NOTE 3 Synonyms for drainage basin include: catchment; catchment area; drainage area; river basin; watershed.

HY_DendriticCatchment	Is narrower than	DrainageBasin In case that HY_Catchment is realized by HY_CatchmentAre a With one outlet	Area having a common outlet for its surface runoff. NOTE 1 Regarding the different classifications of drainage basins, no distinction is made between drainage basins / sub-basins since this will vary with application. It is possible to build basins from other basins. NOTE 2 The outlet of a drainage basin may be a canal or a lake. NOTE 3 Synonyms for drainage basin include: catchment; catchment area; drainage area; river basin; watershed.
HY_InteriorCatchment		Not represented	
HY_CatchmentAggregate	Is like	RiverBasin In case that HY_Catchment is realized by HY_CatchmentAre a	The area of land from which all surface run-off flows through a sequence of streams, rivers and, possibly, lakes into the sea at a single river mouth, estuary or delta. In INSPIRE, the largest 'DrainageBasin' in a system is a 'RiverBasin'
HY_HydroNexus	Is like	HydroNode	A node within the hydrographic network. NOTE May represent a physical confluence, bifurcation/confluence/vanishing point etc., or it may be associated with a hydrographic point of interest or facility. Note that INSPIRE mandates HydroNode to have a geometry (GM_Point)

HY_HydroLocation	Is like	HydroNode/ HydroPOI (depending on the useCase)	<p>In INSPIRE HydroNode and HydroPOI could (but not always) correspond to the representation of the same object. In case, they are disjoint representations, a choice will have to be made on a use case basis</p> <p>HydroPOI def: A natural place where water appears, disappears or changes its flow.</p> <p>EXAMPLE Fluvial points (waterfall, cascade, rapids, breaker), spring/water hole (spring, source, geyser, thermal spring, natural fountain, well, also fumarole, artesian), sinkhole (sinkhole, drainage loss).</p> <p>NOTE A hydro point of interest may create a flow constriction in the network.</p> <p>Note that INSPIRE does not consider monitoring devices (ex : hydrometricStation) as a specific HydroPOI</p>
HY_CatchmentRealization		Not represented	
HY_CatchmentArea	Is like	DrainageBasin	<p>Area having a common outlet for its surface runoff.</p> <p>NOTE 1 Regarding the different classifications of drainage basins, no distinction is made between drainage basins / sub-basins since this will vary with application. It is possible to build basins from other basins.</p> <p>NOTE 2 The outlet of a drainage basin may be a canal or a lake.</p> <p>NOTE 3 Synonyms for drainage basin include: catchment; catchment area; drainage area; river basin; watershed.</p>
HY_CatchmentDivide		Not represented	

HY_CartographicRealization		Not represented	
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E.2. Hydrographic Network Model

HY_Features Name	Relationship between concepts	INSPIRE Hydrography Feature Name + potential condition(s)	Definition / Description
HY_Hydrographic Network		Not represented	INSPIRE has no explicit notion of aggregation of HY_WaterBody (INSPIRE:SurfaceWater) to compose such network.
HY_WaterBody	Is like	SurfaceWater	Any known inland waterway body. EXAMPLE Lake/pond, reservoir, river/stream, etc.
HY_ChannelNetwork	Is narrower than	WatercourseLinkSequence	A sequence of watercourse links representing a non-branching path through a hydrographic network.
HY_Depression		Not represented	
HY_Channel	Is narrower than	WatercourseLink	A segment of a watercourse within a hydrographic network. NOTE A watercourse link may be fictitious, with no direct correspondence to a real-world object and included only to ensure a closed network.
HY_Reservoir	Is narrower than	StandingWater	A body of water that is entirely surrounded by land. NOTE It may occur in a natural terrain depression in which water collects, or may be impounded by a dam, or formed by its bed being hollowed out of the soil, or formed by embanking and/or damming up a natural hollow (for example: by a beaver dam). It may be connected to inflowing / outflowing watercourses or other standing waters.

HY_FlowPath	Is like	WatercourseLink	A segment of a watercourse within a hydrographic network. A watercourse link may be fictitious, with no direct correspondence to a real-world object and included only to ensure a closed network.
HY_LongitudinalSection		Not represented	
HY_CrossSection		Not represented	
HY_WaterBodyStratum		Not represented	
HY_Water_LiquidPhase		Not represented	
HY_Water_SolidPhase		Not represented	

Annex F: HY_Features- SANDRE Mapping

This is a descriptive mapping for the French National Service for Water Data and Reference-dataset Management (SANDRE) [12] on the basis of the data model describing the national dataset called 'BD Carthage' [14]. All element name used corresponds to the XML tag appearing in the data model (not attribute name appearing in BD Carthage).

It is intended to provide an understanding of the basic relationship of HY_Features concepts and the SANDRE hydrologic feature dictionary for Hydrography.

Please notice that terms for SANDRE are based on French words.

F.1. Catchment Model

HY_Features Name	SANDRE Name	Comment
HY_Catchment	RegionHydro OR SecteurHydro OR SousSecteurHydro OR ZoneHydro	SANDRE makes distinction between basins and various sub-basins that are aggregated according to the national hydrographic codification scheme. All those levels can be seen as equivalent to 'contracted catchment' in AHGF in the sense that there is a contract on the catchment ID to represent a given catchment.
HY_DendriticCatchment	RegionHydro OR SecteurHydro OR SousSecteurHydro OR ZoneHydro	SANDRE: all catchments are dendritic
HY_InteriorCatchment	Not represented	All the 'contracted' catchments identified within the French data model are considered to flow to a single common outlet.
HY_CatchmentAggregate	RegionHydro OR SecteurHydro OR SousSecteurHydro	SANDRE: RegionHydro are aggregation of SecteurHydro that are aggregation of SousSecteurHydro that are aggregation of ZoneHydro
HY_HydroNexus	NoeudHydrographique	Can be seen as a specific NoeudHydrographique. Thus narrower than NoeudHydrographique
HY_HydroLocation	NoeudHydrographique	Can be seen as a specific NoeudHydrographique. SANDRE does not consider monitoring devices (ex : hydrometricStation) as a specific NoeudHydrographique
HY_CatchmentRealization	Not represented	

HY_CatchmentArea	RegionHydro OR SecteurHydro OR SousSecteurHydro OR ZoneHydro	While the polygon representing a catchment might be thought of as an area, the subset of a DEM or another land cover dataset would be more in line with the meaning of CatchmentArea.
HY_CatchmentDivide	LimiteHydroBassin	LimiteHydroBassin is the boundary of highest catchments in the catchments hierarchy. For France mainland, it basically corresponds to the 6 big watershed dividing it (Loire, Seine, É). It has a linear representation.
HY_CartographicRealization	Not represented	

F.2. Hydrographic Network Model

HY_Features Name	SANDRE Name	Comment
HY_Hydrographic Network	Not represented	<p>Within SANDRE Channel/Waterbody are not disjoint.</p> <p>SANDRE focuses HY_ Waterbody(ies) which identifiers are based on HY_Channel containing them.</p> <p>Those HY_Channel have HY_Waterbody(ies) which are permanent, intermittent, absent for a long period of time.</p> <p>Thus permanent identifiers assigned to HY_Channel(s) are usually used as 'proxy' to refer to given well known body of waters (HY_WaterBody).</p>
HY_WaterBody	Not represented	
HY_ChannelNetwork	CoursEau OR TronconHydrographique	<p>SANDRE: CoursEau is an aggregation of TronconHydrographique that is an aggregation of TronconHydrographElt.</p> <p>All of them have a linear representation.</p>
HY_Depression	EntiteHydroSurface OR EltHydroSurface	SANDRE: EntiteHydroSurface is an aggregation of EltHydroSurface. Both have a surfacic representation.
HY_Channel	TronconHydrographique OR TronconHydrographElt OR EltHydroSurface	SANDRE: CoursEau is aggregation of TronconHydrographique that is an aggregation of TronconHydrographElt. All of them have a linear representation.

HY_Reservoir	EntiteHydroSurface OR EltHydroSurface OR PointEauIsole	SANDRE: EntiteHydroSurface is an aggregation of EltHydroSurface. Both have a surfacic representation. A subset of PointEauIsole can be used in case that a HY_Reservoir is not linked to the hydrographic network and is represented by a point
HY_FlowPath	CoursEauPrincipal	Each HY_Catchment equivalent in SANDRE (RegionHydro, É) identifies its main HY_ChannelNetwork which provides a hook to providing HY_FlowPath
HY_LongitudinalSection	Not represented	
HY_CrossSection	Not represented	
HY_WaterBodyStratum	Not represented	
HY_Water_LiquidPhase	Not represented	
HY_Water_SolidPhase	Not represented	

F.3. Hydrometric Network

HY_Features Name	SANDRE Name	Comment
HY_HydrometricNetwork	Not represented	
HY_HydrometricFeature	Not Represented	
HY_IndirectPosition	Not represented	

Annex G: HY_Features - NHN Mapping

This is a descriptive mapping for the Canadian National Hydrography Network [13]. It is intended to provide an understanding of the basic relationship of HY_Features concepts and the NHN hydrologic feature types.

G.1. Catchment Model

HY_Features Name	NHN Name	Comment
HY_Catchment	work unit, or Water Survey of Canada Drainage Areas, Sub-Drainage Areas and Sub-Sub Drainage Areas	1356 work units covering Canada have been defined. The Water Survey of Canada has redefined these as a hierarchy with sub-sub-drainage areas corresponding to the work units. The sub-sub-drainage areas are roughly comparable to HUC-8's in the NHD. Catchments are also being defined based on best available data for each of roughly 2200 water gauge stations across Canada; however, initially these catchments will not always be aligned to the NHN. So in practical terms, Canada does not have an equivalent to a HY_Catchment, with its membership in a catchment coverage and its integrated relationship to a hydrographic network. (However, British Columbia's Freshwater Atlas (FWA) does have complete coverage of reach catchments, which were determined algorithmically; the FWA was the source for NHN in BC. Ontario has also developed catchment capabilities based on user provided points on a stream.)
HY_DendriticCatchment	Not represented	
HY_InteriorCatchment	Not represented	
HY_CatchmentAggregate	Not represented	
HY_HydroNexus	HydroJunction	A hydro junction corresponds to a confluence; however, it is not specifically related to a catchment (area). If a network linear flow is thought of as a catchment, then the HydroJunction could be thought of as a hydro nexus id. NHN does not track catchment or hydro nexus identity.
HY_HydroLocation	HydroJunction, man made feature and obstacle.	Since linear referencing is no longer supported, the hydro junctions, man made features, and obstacles are simply a points that can be thought of as hydro locations without network location.
HY_CatchmentRealization	Not represented	
HY_CatchmentArea	Not represented	

HY_CatchmentDivide	Not represented	
HY_CartographicRealization	A map of work units or Water Survey of Canada drainage areas.	Cartographic realization only applies to maps of work units or Water Survey of Canada hierarchical drainage areas or the newly defined drainage areas associated with hydrometric stations.

G.2. Hydrographic Network Model

HY_Features Name	NHN Name	Comment
HY_Hydrographic Network	Waterbodies and single line watercourses that correspond to a collection of network linear flows	The waterbodies and single line watercourses all have corresponding network linear flows. (Double line streams and lakes are waterbodies that are also realized by skeleton lines, which are considered as inferred network linear flows.) As noted earlier though the NHN networks are not tied to catchments or aggregations of catchments.
HY_WaterBody	Waterbodies and single line watercourses.	Waterbody is used specifically for hydrographic features that are represented by polygons: lakes and double-line streams, defined by banks and delimiters. Single line watercourses also fall under HY_WaterBody.
HY_ChannelNetwork	Not represented	See the comment below under HY_Channel.
HY_Depression	Not represented	The NHN has lakes, but does not use the term depression.
HY_Channel	Not represented	The NHN does not have channels as distinct from the hydrographic network. Specifically the properties lists for HY_Channel are not available.
HY_Reservoir	Waterbodies that are reservoirs	The NHN has waterbodies that can be categorized as reservoirs.
HY_FlowPath	Network linear flow	Network linear flows are complete, including secondary flows around islands and constructed flows through wetlands and dams.
HY_LongitudinalSection	Not represented	
HY_CrossSection	Not represented	
HY_WaterBodyStratum	Not represented	
HY_Water_LiquidPhase	Not represented	
HY_Water_SolidPhase	Not represented	

G.3. Hydrometric Network

HY_Features Name	NHN Name	Comment
HY_HydrometricNetwork	Not represented	
HY_HydrometricFeature	Not Represented	
HY_IndirectPosition	Not represented	

Annex H: Revision History

Date	Release	Author	Paragraph modified	Description
08.10.2014	0.1	Irina Dornblut	Initial version	Initial draft in OGC template
12.11.2014	0.2	Irina Dornblut	Section 7, Annex D included	Editing requirements classes, Annex D included
15.08.2016	0.3	David Blodgett; Irina Dornblut	Completely revised version	Draft in OGC template
18.08.2016	0.4	Irina Dornblut	Section 6	Catchment + UML figures added
31.08.2016	0.5	David Blodgett, Darren Smith, David Arctur	Entire Document	General edit for clarity and consistency.
12.09.2016	0.6	Irina Dornblut	Entire document	More edits for clarity and consistency Translation into American English
11.10.2016	0.7	HYF-SWG at Orlando TC meeting Irina Dornblut	Entire Document	Reconciling comments from the initial OAB review Review of conformance and requirements classes Conformance to OGC Abstract Specification standards Edits for consistency
11.10.2016	0.8	David Blodgett	Entire Document	Figures updated Edits for clarity

Date	Release	Author	Paragraph modified	Description
11.18.2016	0.9	Josh Lieberman David Blodgett	Entire Document	Edits in reference to conformance and topological concepts. Class associations, attributes, and constraints formatted into tables. Conformance classes clarified.
9.01.2017	0.10	Irina Dornblut	Section 6 and 7	Reconciling comments from the second OAB review
06.01.2017	0.11	David Blodgett Irina Dornblut	Entire Document	Reconciled issues raised in public comment.

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