

Hydrologic Modeling and River  
Corridor Applications of HY\_Features  
Concepts

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# Table of Contents

1. Subject	6
2. Executive Summary	7
2.1. Document Contributor Contact Points	7
2.2. Foreword	8
3. References	9
4. Terms and definitions	10
5. Overview	12
6. Use Cases	13
6.1. Hydrologic Model Control Volume Definition	13
6.2. Hydrologic Network Connectivity	13
6.3. Characterization of Catchments with Landscape and Atmospheric data	14
6.4. River Corridor Characterization	14
6.5. Hydrologic Location	15
6.6. Flow Network Location	15
7. Use Case Information Requirements	16
7.1. Use Case Information Summaries	16
7.1.1. Hydrologic Model Control Volume Definition	16
7.1.2. Hydrologic Network Connectivity	17
7.1.3. Characterization of Catchments with Landscape and Atmospheric Data	19
7.1.4. River Corridor Characterization	20
7.1.5. Hydrologic Location	21
7.1.6. Flow Network Location	22
7.2. Information Summary	23
7.2.1. Domain Detail and Attributes	24
7.2.2. Hydrologic Realizations	25
7.2.3. Features	25
7.2.4. Topology	27
8. Logical Model	29
8.1. Geospatial Frameworks for Hydrologic Modeling	29
8.2. River Corridor Data Integration	30
8.3. Realization Relations	33
9. HY_Features Change Requests	36
9.1. Realization and Inheritance	36
9.2. Frontal and Inland Sink Nexus Types	36
9.3. Flowline Feature and Linear Referencing	36
9.4. Catchment and Hydrogeologic Unit Interface	37
Appendix A: PlantUML Source for Logical Model	38
A.1. Conceptual to logical model relations	38

A.2. Cross Section Conceptual to Logical relations.....	38
A.3. HY_Features Flowline Detail .....	39
A.4. Hydrofabric Logical Classes .....	40
A.5. Realization relations including dropped classes .....	41
A.6. Realization relations .....	42
A.7. River Corridor Logical Classes .....	43
Appendix B: Revision History .....	45
Appendix C: Bibliography .....	46

# Chapter 1. Subject

Hydrologic geospatial data products contain geometries that represent features such as river segments and incremental catchments. The combination of these provides a 2D (XY) geospatial fabric (hydrofabric) that discretizes the landscape and flow network into hydrologically relevant features at a defined level of scale, resolution, or organization. Hydrofabrics have been created at the national and continental scale in many parts of the world. This engineering report presents progress on formalizing a hydrofabric for drainage basins that adheres to HY\_Features concepts with a focus on the use of the concepts in modeling hydrologic processes. Furthermore, this report documents efforts to integrate river corridor data with the traditionally 2D hydrofabric representations. River corridors include the channel and adjacent land required to maintain or restore a dynamic geomorphic equilibrium.

# Chapter 2. Executive Summary

The WaterML2: Part 3 - Surface Hydrology Features (HY\_Features) Conceptual Model was published by OGC in 2018. This report documents the use of HY\_Features concepts in support of two key tasks: (1) local to continental hydrologic modeling; and (2) referencing river corridor data to hydrographic networks. The presented use cases are applicable in hydroscience research and assessments, water resources engineering practices, and drought and flood responses.

Before the HY\_Features conceptual model there was no internationally recognized standard for the design of software and data for the hydroscience and engineering community. This report presents progress towards a logical data model that interprets the abstract HY\_Features concepts for use in geospatial workflows, modeling applications, and web data systems that integrate hydrologic data.

The use cases addressed include: (1) hydrologic model control volume definition; (2) hydrologic network connectivity; (3) characterization of catchments with landscape and atmospheric data; (4) river corridor characterization; (5) hydrologic location; and (6) flow network location. Each use case is described briefly along with an analysis of the information requirements. This report presents a summary of the logical model designed to satisfy the needs of these use cases and a summary of updates and changes proposed for HY\_Features.

Changes for consideration by the HY\_Features Standards Working Group include the following.

1. Provide more clarity on the inherited properties and associations of features that "realize" the catchment and nexus concepts from HY\_Features.
2. Add nexus realization feature types to represent the outlet of catchments that are "frontal" (terminate to the ocean or a large waterbody) or "inland sinks."
3. Add a "HY\_Flowline" feature as a superclass of HY\_Flowpath providing linear referencing on waterbodies that are not catchment realizations.
4. Add an association or interface to support connection between surface catchments and hydrogeologic units.

## 2.1. Document Contributor Contact Points

All questions regarding this document should be directed to the editor or the contributors.

### Contacts

Name	Organization	Role
David Blodgett	U.S. Geological Survey	Editor
J. Michael Johnson	Lynker - NOAA Affiliate	Editor
Andy Bock	U.S. Geological Survey	Contributor
Jessica LeRoy	U.S. Geological Survey	Contributor
Martyn Wernimont	Contractor to the U.S. Geological Survey	Contributor

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# Chapter 3. References

The following normative documents are referenced in this document.

- OGC: [OGC 16-032r2 WaterML 2: Part 4 – GroundWaterML 2 \(GWML2\) – Version 2.2](http://docs.openeospatial.org/is/16-032r2/16-032r2.html) [<http://docs.openeospatial.org/is/16-032r2/16-032r2.html>]
- OGC: [OGC 14-111r6 WaterML 2: Part 3 - Surface Hydrology Features \(HY\\_Features\) - Conceptual Model](https://docs.openeospatial.org/is/14-111r6/14-111r6.html) [<https://docs.openeospatial.org/is/14-111r6/14-111r6.html>]
- OGC [Abstract Specification Topic 5, Features \(aka ISO 19101:2002, Geographic Information — Reference Model\), 2002](https://portal.ogc.org/files/?artifact_id=29536) [[https://portal.ogc.org/files/?artifact\\_id=29536](https://portal.ogc.org/files/?artifact_id=29536)]

# Chapter 4. Terms and definitions

For the purposes of this report, the definitions specified in Clause 4 of the HY\_Features conceptual model standard OGC 14-111r6 [[https://docs.openeospatial.org/is/14-111r6/14-111r6.html#\\_terms\\_and\\_definitions](https://docs.openeospatial.org/is/14-111r6/14-111r6.html#_terms_and_definitions)] shall apply with the addition of the following terms and definitions.

## Drainage Basin

Like the catchment feature type, a drainage basin is a holistic feature defined as the total upstream area draining to an outlet. It is comparable to a catchment with no inflows and a single outlet. Drainage basins can be thought of as the total accumulated or total upstream catchment and can be described with a pair of locations defining: 1) the headwater area with no discernible flowpaths where flow initiates; and 2) the outlet where flow enters a larger river, waterbody (including oceans), or inland sink. A single mainstem flowpath connects a drainage basin's headwater to its outlet. See [1] for additional discussion.

## Flowline

A flowline is a one-dimensional (linear) feature that represents a flowing body of water and is functionally similar to a flowpath but does not realize the catchment concept and as such does not have flow from or to a hydrologic nexus. A flowline should be thought of as a hydrographic connector with an inlet and an outlet that does not receive lateral flow from a hydrologic unit.

## Headwater

A headwater is scale-dependent and represents the most upstream location where water can exist in a drainage basin or catchment where flow initiates. Such a point is typically along a drainage basin boundary. Given that the definition of a flowpath does not necessitate the existence of water, headwater can be imagined as a point where an extended flowpath touches a drainage basin boundary. See [1] for additional discussion.

## Hydrologic Geospatial Fabric | Hydrofabric

A hydrologic geospatial fabric (hydrofabric) discretizes a landscape according to hydrologic processes and the hydrologic network that conveys water and its constituents downstream. This integration of spatially extensive *catchments* and an expansive network of *flowpaths* enables integration of landscape and river data for hydroscience applications. Conceptually, a hydrofabric includes hydrogeologic features and their association to surface hydrologic features but these associations are not typically represented in most current hydrofabrics.

## Mainstem

The mainstem concept extends and constrains the concept of a flowpath by designating a single path from headwater to outlet through a drainage basin. In other words, a mainstem is a linear realization or backbone of a drainage basin. See [1] for additional discussion.

## River Corridor

A river corridor is part of a fluvial system that includes the landscape of streams, floodplains, and wetlands that are connected by surface water and/or groundwater and function as a continuum

longitudinally and laterally with exchanges of mineral and organic components as water flows downstream to a lower elevation under the force of gravity. See [\[2\]](#) for additional discussion.

# Chapter 5. Overview

Section 6: [Use Cases](#) introduces the use cases considered for this engineering report. They involve hydrofabric definition for hydrologic modeling and river corridor data integration.

Section 7: [Use Case Information Requirements](#) provides important details for understanding the use cases.

Section 8: [Logical Model](#) outlines the logical data model used in experiments and ongoing development activities.

Section 9: [HY\\_Features Change Requests](#) summarizes the findings in relation to the HY\_Features baseline concepts.

# Chapter 6. Use Cases

This report concerns two top level use cases:

1. geospatial frameworks for hydrologic modeling; and
2. river corridor data integration.

These use cases have considerable overlap but serve very different goals. The [Hydrologic Model Control Volume Definition](#), [Hydrologic Network Connectivity](#), and [Characterization of Catchments with Landscape and Atmospheric data](#), and [River Corridor Characterization](#) use cases align directly with the top-level summary use cases. The [Hydrologic Location](#) and [Flow Network Location](#) are applicable to both. Locating information assets along hydrologic flowpaths is the primary area of overlap. Together, these use cases are representative of a complete "hydrofabric," which encompasses both the hydrology and the river corridor specific use cases.

The following sections describe a collection of use cases that illustrate the two summary use cases. Each begins with a relatively specific example followed by more general discussion of the use case.

## 6.1. Hydrologic Model Control Volume Definition

Hydrologic modelers need to define spatial features (catchments) to be used as control volumes for water budget calculations. Each unit may produce excess runoff that must be "routed" through downstream catchments.

In hydrologic analysis, the concept of a control volume is a common abstraction used to track the fluxes and state variables of a physical system. The catchment is a hydrology-specific control volume with specific characteristics: a realized flowpath connecting inflow (or headwater) to outflow; and an area bounded by a divide that connects landscape processes to a flow network.

The factors defining a control volume go beyond the scope of this report. However, the characteristics of the spatial features that can be altered to meet provided objectives include catchment area and flowpath length. A catchment can be made larger by encapsulating (aggregating) more tributary networks or smaller by splitting the catchment and realized flowpath into one or more smaller catchment features.

## 6.2. Hydrologic Network Connectivity

A hydrologist will often need to find information such as monitoring data upstream or downstream of an unmonitored study location in order to predict hydrologic behavior. The network upstream of a location may also be used to accumulate landscape characteristics to further aid in predicting water quantity or quality at an unmonitored location.

When represented as a collection of areas, catchments form a continuous feature coverage that partitions the landscape into hydrologic units. This coverage can have a connected graph of realized flowpaths that define the hydrologic network. This hydrologic network can be used to define control volumes for models of flowing water and as a reference system for hydrologic locations such as streamgages, water intakes, bridges, and other application relevant on-network

features. The hydrologic network can be thought to exist whether a channel contains water at all times or not. With this in mind, methods for determining connectedness are beyond the scope of this report.

A hydrologic network enables four common operations (sub-use cases).

1. Network navigation, where network connections are followed to find hydrologically connected features, or to subset a drainage basin for a known outlet.
2. Accumulation, where the network is used to infer accumulation of attributes or flow constituents along the network. This application is similar to activities like [EPA's StreamCat program](<https://www.epa.gov/national-aquatic-resource-surveys/streamcat-dataset>) [3].
3. River identification, where the network connectivity is used to infer collections of flowpaths that make up the main path of a river within a drainage basin.
4. Hydrologic addressing, where locations of interest can be associated with the hydrologic network to query control volumes, inject structural information about the network, or initialize river identification or network navigation.

### **6.3. Characterization of Catchments with Landscape and Atmospheric data**

A water quality analyst may need to know the percent coverage and spatial distribution of landscape characteristics (e.g., agricultural practices, impervious area, or shallow groundwater) in the catchments of a hydrologic geospatial fabric so they can make estimates of water quality in a downstream location.

Catchment characterization is a key use case for hydrologic modeling and related applications. For this use case, a catchment divide polygon is used as a spatial unit to subset static or time-varying spatial data (e.g., landscape, geology, and atmospheric data). In hydrologic modeling, catchment characteristics are used as model parameter estimates, meteorological forcing inputs, or baselines to inform calibration. In other applications, catchment characteristics can be used directly in an analysis or decision process (determining presence or absence of certain conditions within a drainage basin, for example).

### **6.4. River Corridor Characterization**

A geomorphologist needs to estimate in-stream and overbank river corridor characteristics to inform sediment transport patterns, plant species distribution, and floodplain elevation zones to better understand and improve floodplain ecosystem functions. This information must be broken up into different ecological, geomorphic, and hydrogeologic zones depending on the hydraulic, ecological, and groundwater setting of the river corridor.

River corridor characterization is important for estimating hydraulic or hydrologic routing models as well as geomorphic, ecosystem, groundwater, and other applications. Unlike catchments, which have an explicit 2D spatial expression, river corridors can be 1-dimensional (e.g., river center line or bank line), 2-dimensional (e.g. a floodplain delineation), or 3-dimensional (e.g., a channel geometry model). Given that a river corridor can have these different representations, the

characteristics that describe them are quite diverse.

## 6.5. Hydrologic Location

An emergency response coordinator needs to know what access locations and sensitive infrastructures lie downstream of a contaminant spill or flood event in order to dispatch monitoring teams and warn infrastructure operators, such as water treatment facilities. Hydrologic locations (river addresses) are essential information in this task.

Hydrologic locations link the network to any data that can be idealized as a point location. Any location that can be located along a flowpath is conceptually a hydrologic location. As a use case, there are two ways to define hydrologic location for modeling and analysis: (1) determining the specific flowpath a location is associated with (hydrologic addressing) and (2) using known locations.

To determine a hydrologic location, river identification (a sub-use case of hydrologic network connectivity) is key, and additional information is often required to determine if a location is on a main river or a nearby tributary. The integration of existing hydrologic locations is a major component of any modeling or analysis that supports assimilating information from sources such as streamgages or that reports information along the network at these locations.

## 6.6. Flow Network Location

A civil engineer responsible for maintaining a navigation channel along a major river must maintain detailed records of cross sections and bathymetries in channels in and among islands in the middle of a major river. The channels are artifacts of sediment transport and dredging and do not have well-defined catchments but are part of a large river system.

In contrast with the hydrologic location use case, flow network locations are not necessarily associated with a catchment or hydrologic network. Rather, they are associated with a flowline feature that forms a hydraulic connection between waterbodies. Determining which flowline a flow network location belongs to is similar to hydrologic location, but accumulated hydrologic attributes such as total drainage area can not be used to disambiguate which flowline the hydrologic location belongs to.

Functionally, flow network locations are more general, and normally a more resolved, version of hydrologic location. The need for this is to locate features such as cross sections or sediment samples along certain branches (flowlines) of rivers rather than locating features such as streamgages on a main stem that monitor flow from the entire drainage basin.

# Chapter 7. Use Case Information Requirements

All above use cases require common information to describe networks of flowing water. Hydrologic phenomena are landscape-wide processes that coalesce into paths of preferential flow (flowpaths and flowlines). Fluvial phenomena are an expression of hydrologic phenomena, yet are confined to river corridors where flowing water interacts with sediment and the ecosystem to form complex flowing systems. Hydrologic phenomena are considerably more abstract and can be studied across the widest range of spatial scales — continental to sub-field.

With this context, the following information types are required for all use cases.

## 7.1. Use Case Information Summaries

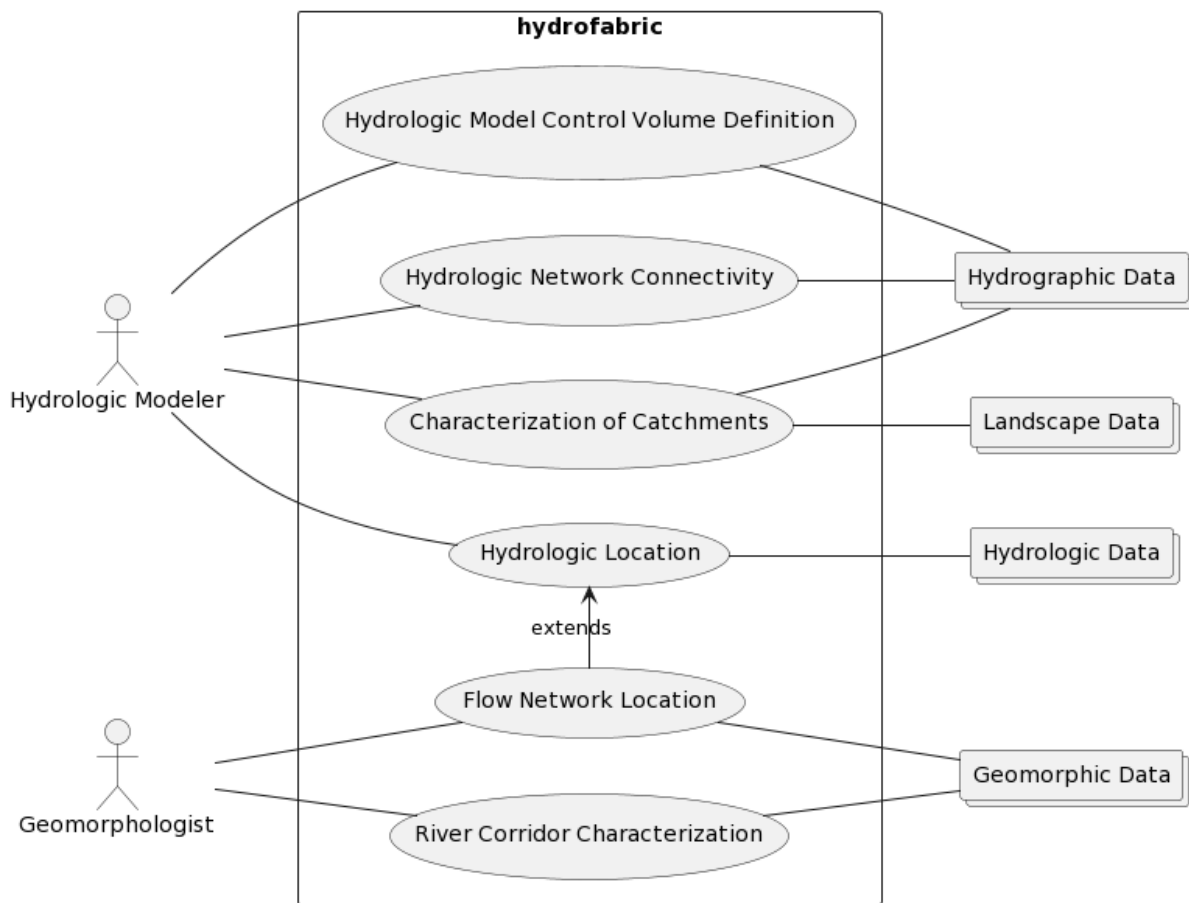
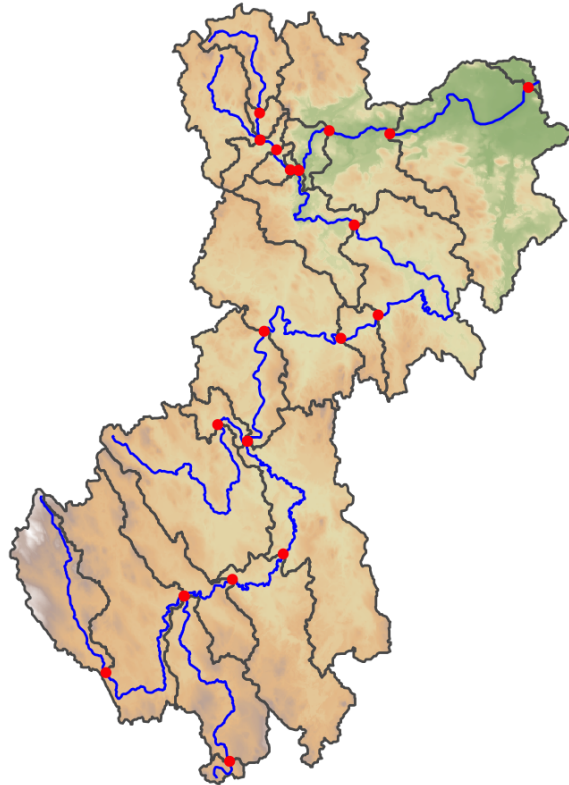


Figure 1. Rudimentary use case diagram for overall hydrofabric use case illustrating domain-specific users and data sources.

### 7.1.1. Hydrologic Model Control Volume Definition

As shown in Figure 1, a hydrologic modeler seeks to understand control volumes at various hydrologic locations. Therefore, a clear and concise knowledge of modeling objectives driven by the spatial domain, functional needs, model complexity, and other factors must be provided; i.e., a collection of important hydrologic locations and a pre-existing catchment network. In many cases, the pre-existing network is an elevation surface (where grid cells act as catchments) and hydrologic

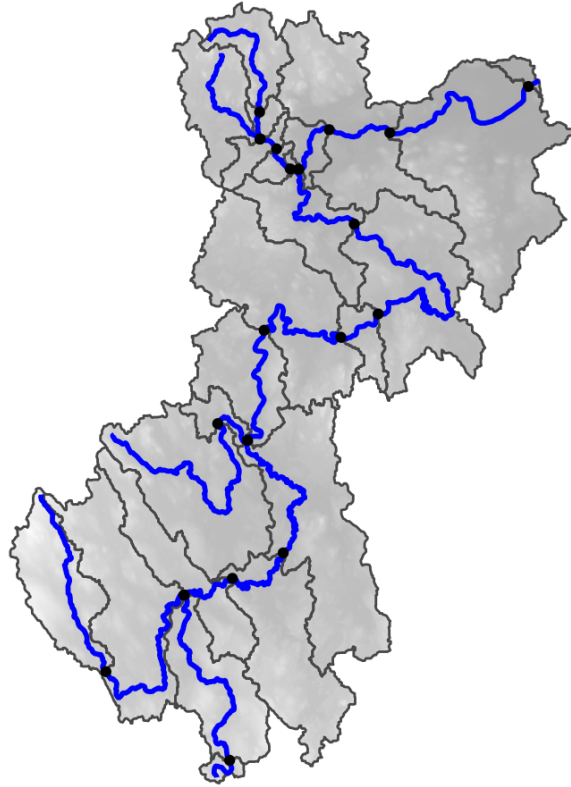
locations are provided "pour points" where catchment outlets are desired.



*Figure 2. A detailed flowpath network, elevation data, a set of pour points (POIs), and the aggregate catchments.*

### **7.1.2. Hydrologic Network Connectivity**

Hydrologic connectivity is typically implicit in hydrographic datasets. That is, the geometric topology of the realized flowpath can be transformed into a feature topology that links realized catchment features. This is true whether the source of geometric topology is a collection of vector geometries or a path of high-flow accumulation derived from elevation data. For this use case, the hydrologic modeler must determine how the hydrologic network should be represented (as an edge list, an edge/node graph, strictly dendritic, etc.) and what hydrographic data are needed to produce the connected network.



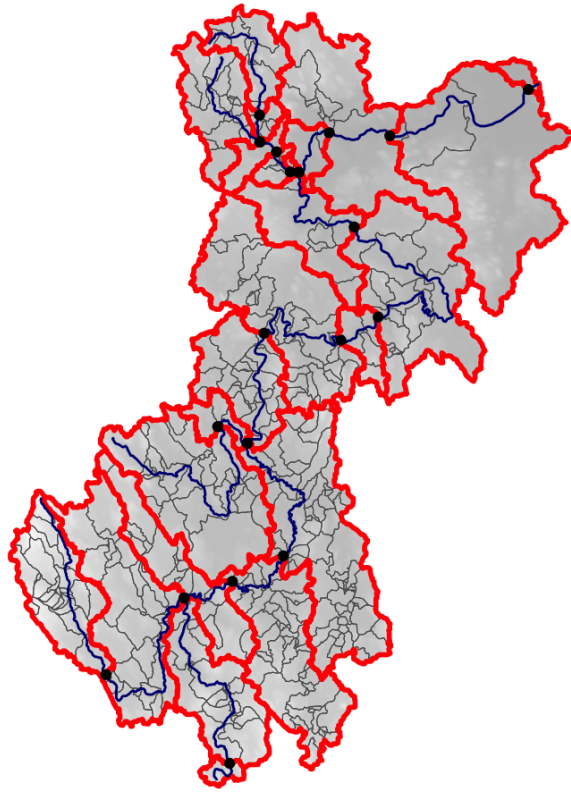
*Figure 3. Flowpaths connect the inlet to the outlet of catchments.*

### **Catchment Aggregates**

Catchment aggregation is the process of "upscaling" a catchment network to a set of larger catchments that encapsulate networks of contained catchments to better meet the needs of a modeling application. This process decreases network resolution without breaking network connectivity while providing a catchment network that better aligns the scale of control volume calculation with the scale of the physical processes being modeled or the locations where reporting model states is most critical.

In practice, aggregation is executed by either resolving a defined set of meaningful hydrologic locations or by resolving a set of uniform catchment aggregates constrained according to the requirements of a modeler or domain expert.

When creating an aggregated network, sets of catchments must be defined for each aggregate catchment and the associated realizations (flowpaths and divides) merged in a way that preserves the overall network connectivity. Additionally, for each aggregate catchment a dominant flowpath must be defined and the associations between the flowpath and divide and the original flowpaths and divides must be described in ways that allow interoperability between the two networks.



*Figure 4. Catchments (red) can be formed by aggregating contained catchments (grey).*

### **7.1.3. Characterization of Catchments with Landscape and Atmospheric Data**

Catchment characterization is the process of summarizing other spatial data to catchment areas through a summary function. In other words, polygonal catchment divides from hydrographic data sources are used to derive characteristics of landscape and geologic phenomena. The resulting values describe a single summary value for the interior of a catchment (HY\_CatchmentArea in HY\_Features terms). For the sake of this report, meteorological and hydrogeological data with a meaningful interaction with the surface are considered to be a type of landscape data that are a time varying "forcing" input.

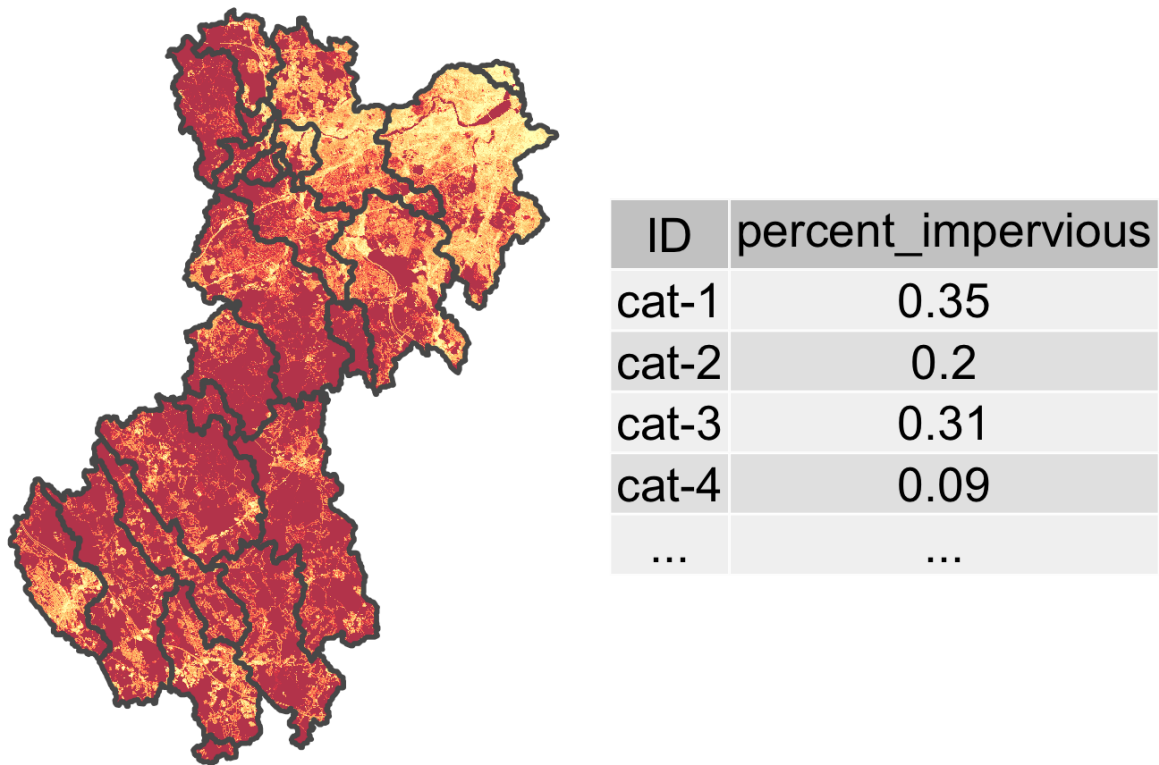


Figure 5. Catchment divides are spatial sampling features for landscape characteristics.

#### 7.1.4. River Corridor Characterization

Like catchment characterization, characterizing a river corridor requires a summarized set of field or coverage datasets for the river corridor region. Characterizing a river corridor is purpose dependent, and must be provided by a geomorphologist or hydroscintist. Part of the required information is the delineated "river corridor" as there is significant diversity in river corridor definitions. Such examples include, but are not limited to, the following.

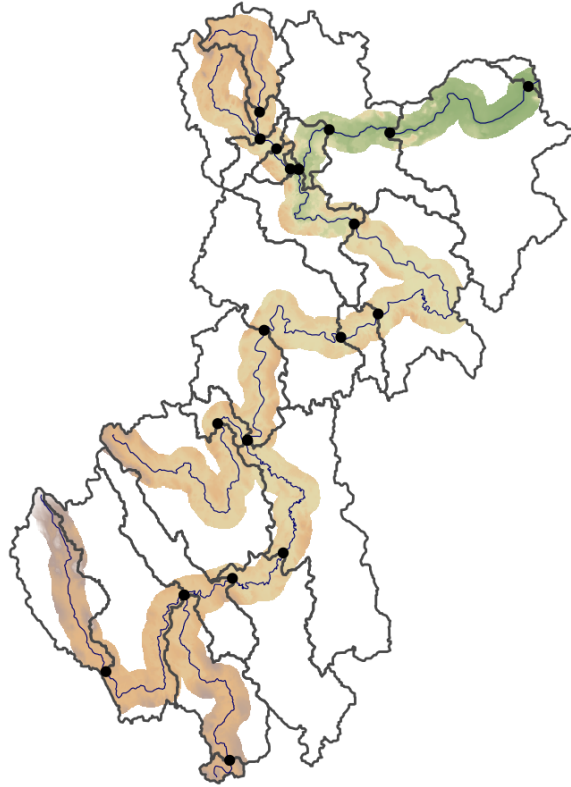


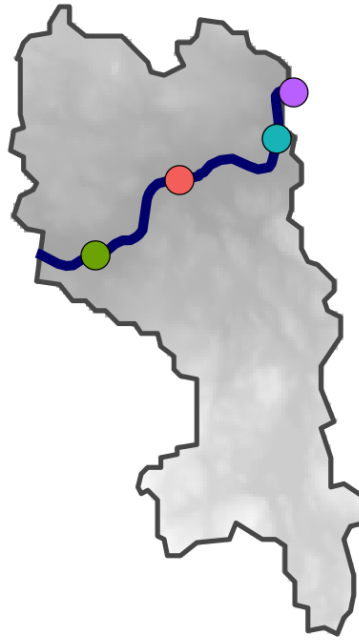
Figure 6. River corridors can be defined many ways and provide a spatial feature for integration with other data.

- Three-dimensional areas of direct interaction between terrestrial and fluvial ecosystems that may interact with groundwater.
- The channel and adjacent land that the river needs to maintain or restore a dynamic geomorphic equilibrium.
- The width of the channel in which water flows and the adjacent land that is subject to the influence of the watercourse into the surrounding landscape (U.S. Federal Emergency Management Agency definition [4]).
- The channel and land surrounding a river that provides for geomorphic and riparian ecosystem functions that may depend on certain hydrogeologic conditions.

Thus, it is assumed that the delineation specification is provided by a domain expert. Figure 1 shows a single "Geomorphic Data" source. However, depending on the specific application, river corridor characterization could concern ecological, hydrodynamic, biogeochemical, hydrogeological, or other domain-specific data sources.

### 7.1.5. Hydrologic Location

Hydrologic locations are located "along" a flowpath of a catchment. Information observed at a hydrologic location can be affected by all catchments that comprise the sub catchments of the location's drainage basin. The process of determining a hydrologic location takes this into account by requiring a hydrologist to determine the appropriateness of a given hydrologic location. On the other hand, a hydrologic modeler may want to find hydrologic data along the network of flowpaths of interest. In this case, a hydrologic location is a pre-existing link between a hydrologic model or analysis and data that are linked to that location.



Hydrolocation Type   ● Facility   ● Gage   ● Intake   ● Outlet

*Figure 7. Hydrologic locations can be seen as watershed outlets and must be along or at the end of the flowpath of a catchment.*

### 7.1.6. Flow Network Location

A flow network location occurs along a flowing body of water that is meaningfully associated with the waterbody or its channel. Establishing a flow network location is similar to establishing a hydrologic location, however the information required to determine a location's appropriateness is geomorphic rather than hydrologic. Any hydrosience application needing information linked to rivers could find utility in data associated with a flow network location. [Figure 1](#) shows a single "Geomorphic Data" source for flow network location. However, this label is used to make a distinction with hydrologic data and could represent a wide array of data types associated with a flow network location.

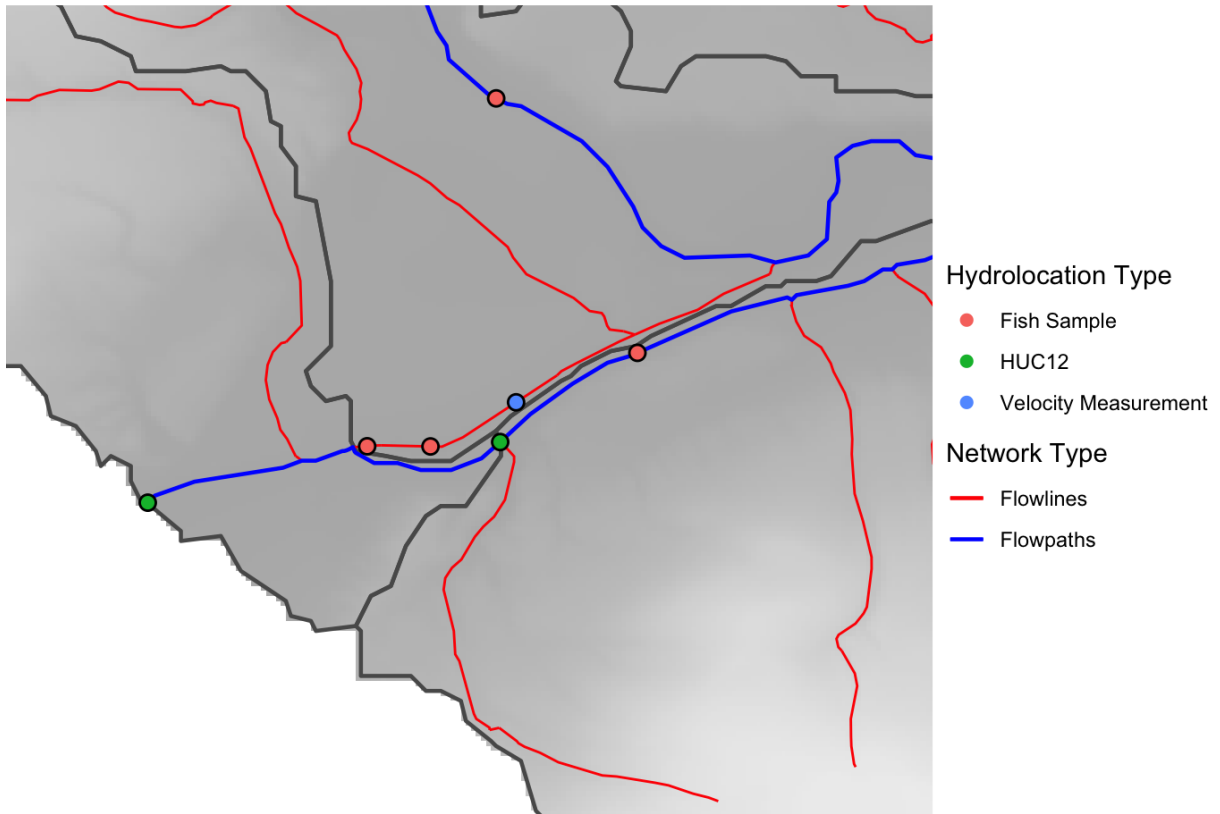


Figure 8. Flow network locations are locations along some flowing body of water.

## 7.2. Information Summary

The following lists information types organized by use case as described above, and how well existing HY\_Features concepts accommodate the needed information.

### Hydrologic Control Volume Definition

- modeling objectives
- a set of hydrologic locations
- predefined catchment network

HY\_Features concepts satisfy this use case with the catchment and nexus concepts. Coastal and inland catchments require nexus realizations that are not easily conceptualized as hydrologic locations, implying the need for additional nexus realization feature types.

### Hydrologic Network Connectivity and Catchment Aggregation

- hydrographic network
- catchment network
- modeling objectives
- hydrologic locations

HY\_Features concepts satisfy this use case with the hydrographic networks (of water bodies) and catchment networks. Aggregated collections are well supported through catchment aggregate

concepts and the hydronetwork catchment realization. While not a critical issue, the lack of a flowline concept (a linear waterbody representation that is not a catchment realization) is notable.

### **Characterization of Catchments with Landscape and Atmospheric Data**

- modeling objectives
- predefined catchment network
- coverage or field datasets
- summary functions

HY\_Features concepts satisfy this use case with the catchment area realization and the ability to identify aggregates of catchment areas. Relationships to groundwater are not directly supported by HY\_Features concepts and must be represented in an ad-hoc way.

### **River Corridor Characterization**

- modeling objectives
- river corridor delineation
- data processing requirements
- coverage or field datasets
- summary functions

HY\_Features concepts satisfy this use case with the flowpath and hydrographic and channel network concepts. The lack of a flowline concept that supports linear referencing of network locations limits the ability to integrate non-hydrologic channels in a flowpath network.

### **Hydrologic Location**

- appropriateness of hydrologic location
- location and attributes of source data

HY\_Features concepts fully satisfy this use case. In representing catchment outlets as hydrologic locations, the extent to which a hydrologic location of type outlet can inherit the properties of a nexus is not specific in HY\_Features, leaving some uncertainty in how to implement a logical model.

### **Flow Network Location**

- appropriateness of flow network location
- location and attributes of source data

HY\_Features concepts for indirect position support this use case but indirect position on linear features that are not realizations of a catchment is a limitation.

## **7.2.1. Domain Detail and Attributes**

Several of the information types can be categorized into "domain details." These details are information provided by an expert in the use case, such as modeling objectives for a given decision,

or necessitated by the requirements of the use case. This information is included only for completeness and to fully describe the separation of concerns an analysis relies on.

Like domain details, information that could be considered attributes are presented only to illustrate a separation of concerns. These "attributes" include physiographic attributes of hydrologic features and constituent or characteristic attributes that might be derived through integrated processing.

## 7.2.2. Hydrologic Realizations

Below we will describe key feature types needed to fulfill the objectives of the listed use cases. However it is important to recognize that HY\_Features defines a catchment as a holistic unit where hydrologic processes can occur. Each catchment, however, can be realized in concrete ways to address specific needs or to encapsulate complexity. Realizations offer variable conceptual representation for the same real world holistic feature. In other words, a feature that is a catchment realization represents one aspect of the catchment that it is a realization of. The flowpath realization represents the aspect of the overall catchment concept that conveys flow from an inflow to an outlet. While the divide realization represents the aspect of the overall catchment concept that bounds landscape area that directly contributes storm flow and/or sediment.

## 7.2.3. Features

The information required for the above use cases are primarily hydrologic and hydrographic features. Features in this context are an "abstraction of real-world phenomena" per [OGC Abstract Specification Topic 5 \[ISO 19101\]](https://www.ogc.org/docs/as/) [https://www.ogc.org/docs/as/]. Although a feature, by this definition, can have a vector geometry representation, the [simple features geometry specification](https://www.ogc.org/standards/sfa/) [https://www.ogc.org/standards/sfa/] does not apply. That is, a feature could have many highly nuanced geospatially tied representations or even no geometric representation at all as in a schematic of a watershed.

### Hydrologic Locations

Hydrologic locations are features such as monitoring locations that occur along a flowpath. By tying these point locations to a hydrologic system, we can associate the entire drainage basin to that point. This is significant both in terms of measuring system response, as with a streamgage, as well as understanding system impacts on infrastructure, as with a bridge.

### Hydrographic Locations

Hydrographic locations are very similar to hydrologic locations, but are not associated with a specific upstream drainage basin. For example, monitoring / sampling locations in a backwater channel of a floodplain do not capture all flow from the upstream basin but are located along a linear flowing waterbody (flowline). Such locations can have an indirect position expressed as some distance along the flowline but this position does not have to be the outlet of a drainage basin.

### Flowpaths

HY\_Features (OGC-16-032r2) defines flowpaths as one of several possible "catchment realizations". A flowpath is a linear geometry that can be associated with a coincident waterbody and channel feature. Both the waterbody and channel concepts of HY\_Features include constraints "*waterbody-flowpath* and *channel-flowpath*" that: "*whenever a flowpath exists as part of a network, the*

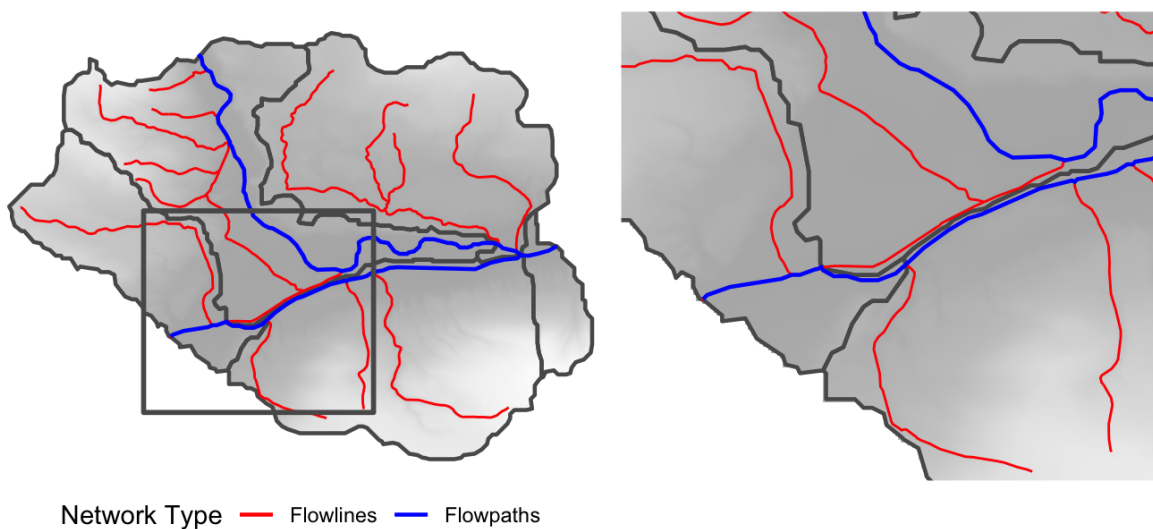
*waterbody [surface depression and surface channel] should be recognized as a flowpath. Geometrically represented as a curve, waterbody-flowpath [channel-flowpath] will support to 'measure' a position on, or along, the waterbody using a centerline as shape."*

As alluded to in the measure detail of the waterbody-flowpath constraint, the flowpath feature is also used as the "linear element" for the indirect position of a hydrologic location. Importantly, **only** the flowpath feature is allowed as the linear element of an indirect position as HY\_Features does not support indirect positioning along a waterbody.

## Flowlines

Flowlines are not, strictly speaking, hydrologic features. They are the result of fluvial geomorphic and human-influenced channelization that divert or otherwise convey water in a way that may go counter to classic dendritic assumptions. In hydrologic analysis, systems of flowlines are either encapsulated within catchments or treated as water withdrawals or additions.

Three specific cases where the "flowline" feature type is useful are: rivers with many channels, alluvial fans and distributary systems in deltas, and natural or built levees. In the first two, an abstract flowpath could provide an idealized representation of how water flows through a catchment. In the third case, however, there are often true "interbasin" transfers where, at some scale, water is diverted outside the catchment and cannot be idealized by a flowpath. In these cases, there is a diverted *flowline* and the receiving flowline does not realize a catchment.



*Figure 9. Illustration of flowpaths that realize the inlet to outlet connectivity of a catchment in blue and the more general flowlines, which may or may not be the flowpath of a catchment, in red.*

In contrast with diverted flowlines, a hydrologic nexus can have more than one receiving flowpath (catchment realization) — causing a hydrologic divergence (a diverted flowpath with an associated catchment not just a diverted flowline). In this case, both receiving flowpaths would have a

catchment and host of catchment realizations.

A logical data model that includes a class adhering to the flowline concepts described here is compatible with the concepts of HY\_Features. This would be achieved through association to surface hydro features that form hydrographic and channel networks. However, since indirect positions can only reference flowpath features there would be no unifying linear representation of channel and waterbody other than flowpath for linear referencing. For this reason, the flowline concept may warrant being added to the HY\_Features conceptual model.

## **Divides**

Catchment divides provide a polygon partition of the landscape. In hydrologic (water budget) modeling, there is an expectation that the partitioning provides a complete coverage of the domain. However, this requirement presents a problem if every catchment is to have a nexus represented by a hydrologic location. This is important in catchment divides that are adjacent to major bodies of water and have no concentrated outflow and also inland (endorheic) catchments with no discernable terminal hydrologic location.

This issue relates to catchment divides in a somewhat indirect way. The requirement that a catchment divide encompasses a frontal or endorheic catchment brings this issue to light. In these cases, a logical or physical data model based on HY\_Features concepts, is forced to create additional (conceptual) nexus realization feature types to accommodate diffuse frontal outflows and outflows of indeterminate internally drained catchments.

## **7.2.4. Topology**

### **Catchment Network**

In HY\_Features, the catchment network model involves a system of catchments and nexuses. A catchment can accept flow from one - and only one - nexus and give flow to one - and only one - nexus. A nexus can take flow from one or more catchments and give flow to one or more catchments. Two important details were encountered in the work leading to this engineering report: 1) headwater catchments can be thought of as graph nodes, and 2) the inclusion of nexuses in the catchment network graph requires that they be represented as edges or that associations between catchments and nexuses be represented as edges. The importance of these two factors is especially relevant when considering that a catchment network has an associated network of features representing flowpath realizations.

In all drainage basins, a flowpath is not discernable in the most upper reaches of the headwater region. Therefore, if an application is to include flowpaths, there must be a threshold at which a flowpath begins. Considering the definition of "HY\_Flowpath" from HY\_Features (OGC 16-032r2): *"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,..."* This definition implies that, for a flowpath to exist, the catchment must have an inflow. For headwater catchments, no inflow exists and no flowpath exists. This logical interpretation of headwater catchments is compatible with the HY\_Features model and could be considered as part of a logical implementation of the concepts.

Given that headwater catchments will have no inflow nexus and no flowpath, representation of a headwater catchment in a graph representation of a catchment network is most naturally accomplished as a graph node. It may feel most intuitive to represent nexuses as nodes and catchments as edges, but in practice, this is not feasible. In fact, if nexuses are included in the network explicitly, a network terminus is always a nexus and, therefore, a graph node as well. The fact that a complete catchment network must start at a headwater with no inflow nexus and terminate with a nexus leads to the finding that a graph implementation of HY\_Features should treat both catchments and nexuses as nodes and the associations between them as edges.

HY\_Features includes one conceptual representation (realization) of the nexus concept, a hydrologic location, which is idealized as a point. If the outlet of a catchment network must be a nexus and that nexus is idealized as a point, coastal (or otherwise "frontal") and indeterminate internal network outlets present a problem. As described in [HY\\_Features Change Requests](#), addition of frontal and internal nexus realization conceptual feature types to HY\_Features may be warranted.

### **Waterbody Network**

A network of waterbodies coexists with a network of catchments and their flowpath representations. The complexity of this relationship can be daunting, but in practice, it can be approached pragmatically. If a flowline is a linear representation of a waterbody and a flowpath is a special type (perhaps a subclass) of flowline, then we can start with a highly resolved network of waterbodies and consider all of those on the main hydrologic path to be flowpaths. The two networks (flowpath and waterbody) then, have an explicit relationship defined by the "main paths" through the waterbody network. Additional network representations (e.g., lidar derived vs legacy DEM derived) can be conflated via the main hydrologic paths. Integration of a complete waterbody network (as opposed to the more general hydrologic network) would require additional, more nuanced, integration.

Integration of hydrologic and waterbody networks is promising to facilitate stability of hydrologic networks and associated data and while enabling interoperability of less persistent (changing or improving) networks of waterbodies. For instance, a system built to track the location of features such as dams, streamgages, hydrologic model intercomparison locations, etc. can exist on a stable backbone of hydrologic features that intersects with one or more representations of channels and waterbodies that relate to the hydrologic network.

A final note on waterbody networks concerns flow connectivity. While a hydrologic network will most often be a directed acyclic graph, a network of waterbodies may not be directed at all. Coastal and confluence environments may have backwater channels that flow either direction. Despite this, the representation of channel bathymetry and location of data along such channels must still be supported. This drives the need for an indirect position capability that takes into account the nuances of non-hydrologic waterbodies.

# Chapter 8. Logical Model

The HY\_Features model provides many of the concepts needed for the described use cases. However, with its emphasis on surface hydrology, it does not provide some required groundwater and non-hydrologic concepts. This section describes the logical data model that was found to be applicable to the development of a U.S. national reference hydrofabric, which supports aggregation for specific applications such as the U.S. Geological Survey National Hydrologic Model (NHM) [5] and the National Oceanic and Atmospheric Administration (NOAA) Next Generation Water Resource Modeling Framework [6] (supporting the National Water Model version 4 [7]). We draw specific attention to concepts that are not a priori available from HY\_Features such as frontal and inland sink nexuses.

## 8.1. Geospatial Frameworks for Hydrologic Modeling

Figure 10 provides an overview of the model hydrofabric logical data model classes, relationships, and key attributes. Note that all classes in the hydrofabric part of the logical model use the `hf_*` convention.

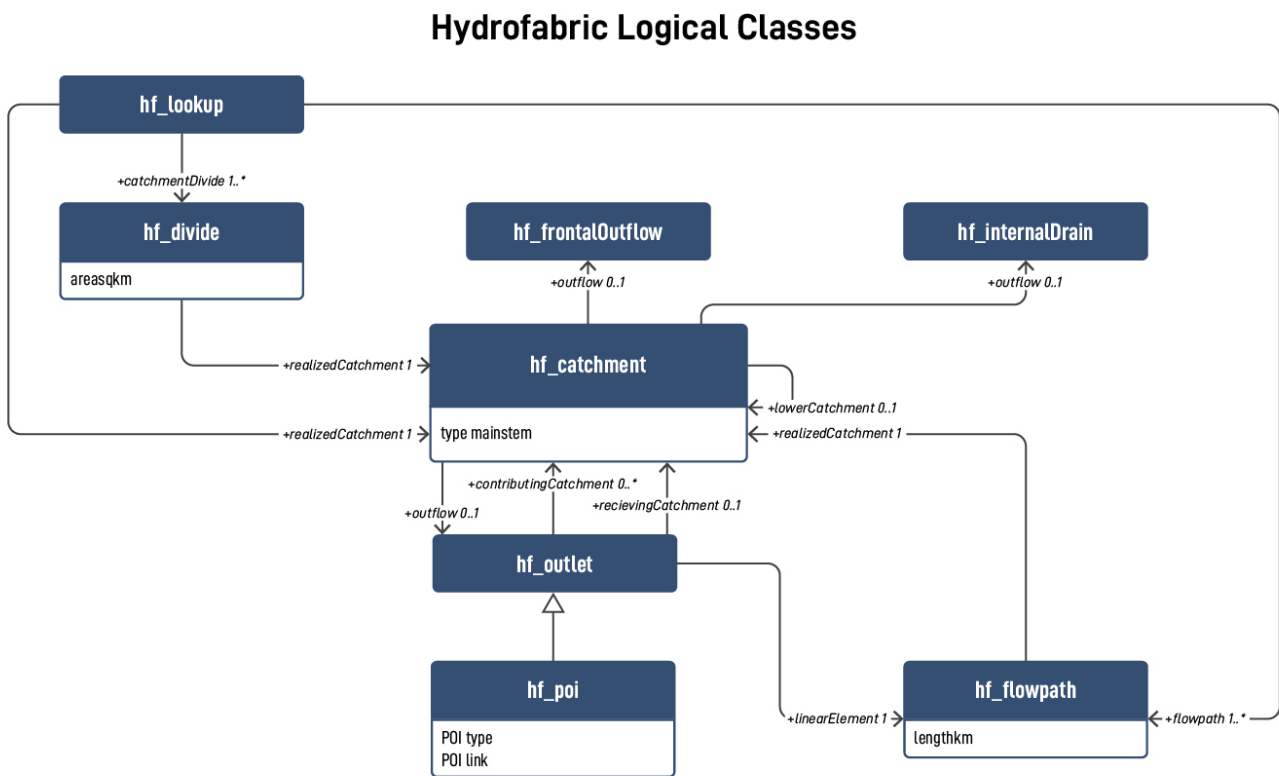


Figure 10. Logical Classes for the Hydrofabric

Figure 11 shows the relationship between HY\_Features concepts and the hydrofabric (hf) logical classes using subclass relations between conceptual and logical model classes.

- `hf_catchment`: Based on the `HY_Catchment` concept. Includes an identifier, a "mainstem" river identifier, and defined type (, coastal, network, internal)
- `hf_outlet`: Based on `HY_HydroLocation` and adopts a contributing and receiving catchment relationships from `HY_Nexus` through the realization relationship.

- hf\_POI: A "Point Of Interest" (POI) is a subclass of hf\_outlet that has importance outside of the hydrofabric. These are generally the hydroLocations defined a priori for the hydrofabric.
- hf\_flowpath: Based on HY\_Flowpath and includes a nominal length attribute, the realized catchment ID, and the network topology (ID/toID).
- hf\_divide: Based on HY\_CatchmentDivide and includes a nominal area attribute.
- hf\_frontalOutflow: No HY\_Features concept for this linear nexus realization in divides that have no concentrated outflow.
- hf\_internalDrain: No HY\_Features concept for this polygonal nexus realization in divides where there is no discernable terminal hydrologic location.
- hf\_lookup: Based loosely on HY\_Hydronegwork to track aggregation relationships for both catchment divides and flowpaths.

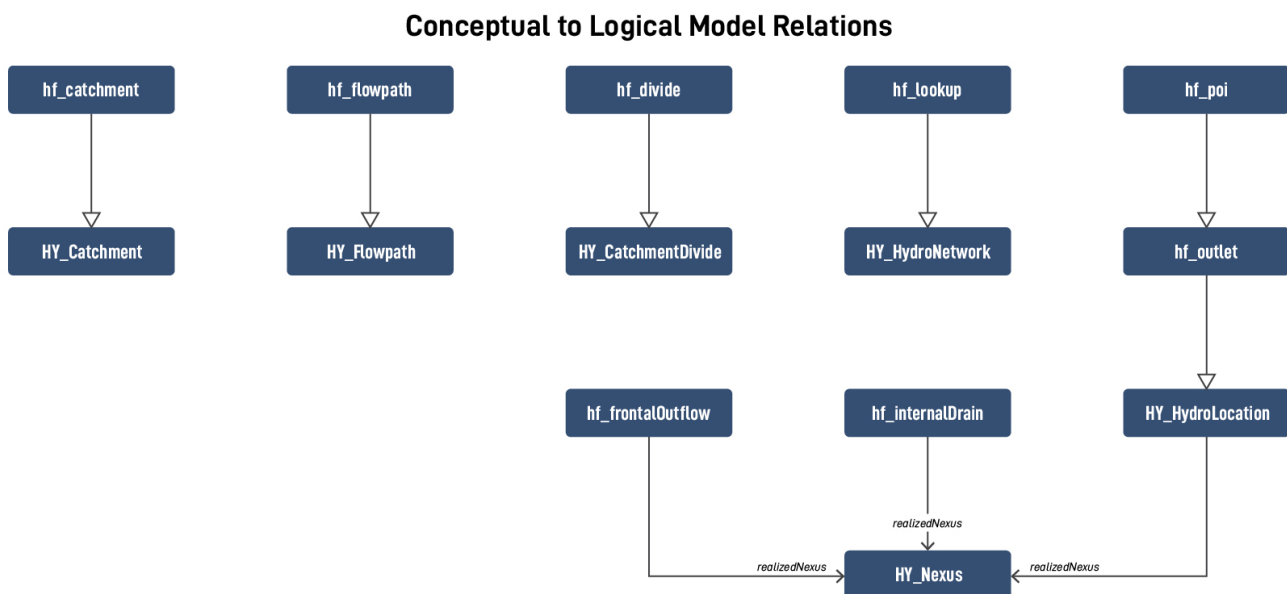


Figure 11. Catchment conceptual to logical model relations showing logical classes as subclasses of conceptual classes.

## 8.2. River Corridor Data Integration

Figure 12 provides an overview of the HY\_Features concepts that are important to cross section referencing. This diagram is included to show how the proposed "HY\_Flowline" concept relates to existing HY\_Features concepts. The channel and hydrographic network classes are included to show that both flowpath and flowline can form associations to networks that are aggregations of channels and/or waterbodies. Cross section and hydroLocation classes are included to show how cross sections, which are critical for the river corridor use case, relate to the broader data model presented in Figure 10. Note that no hydrogeologic classes are shown and could be the subject of future work.

## HY\_Features Flowline Detail

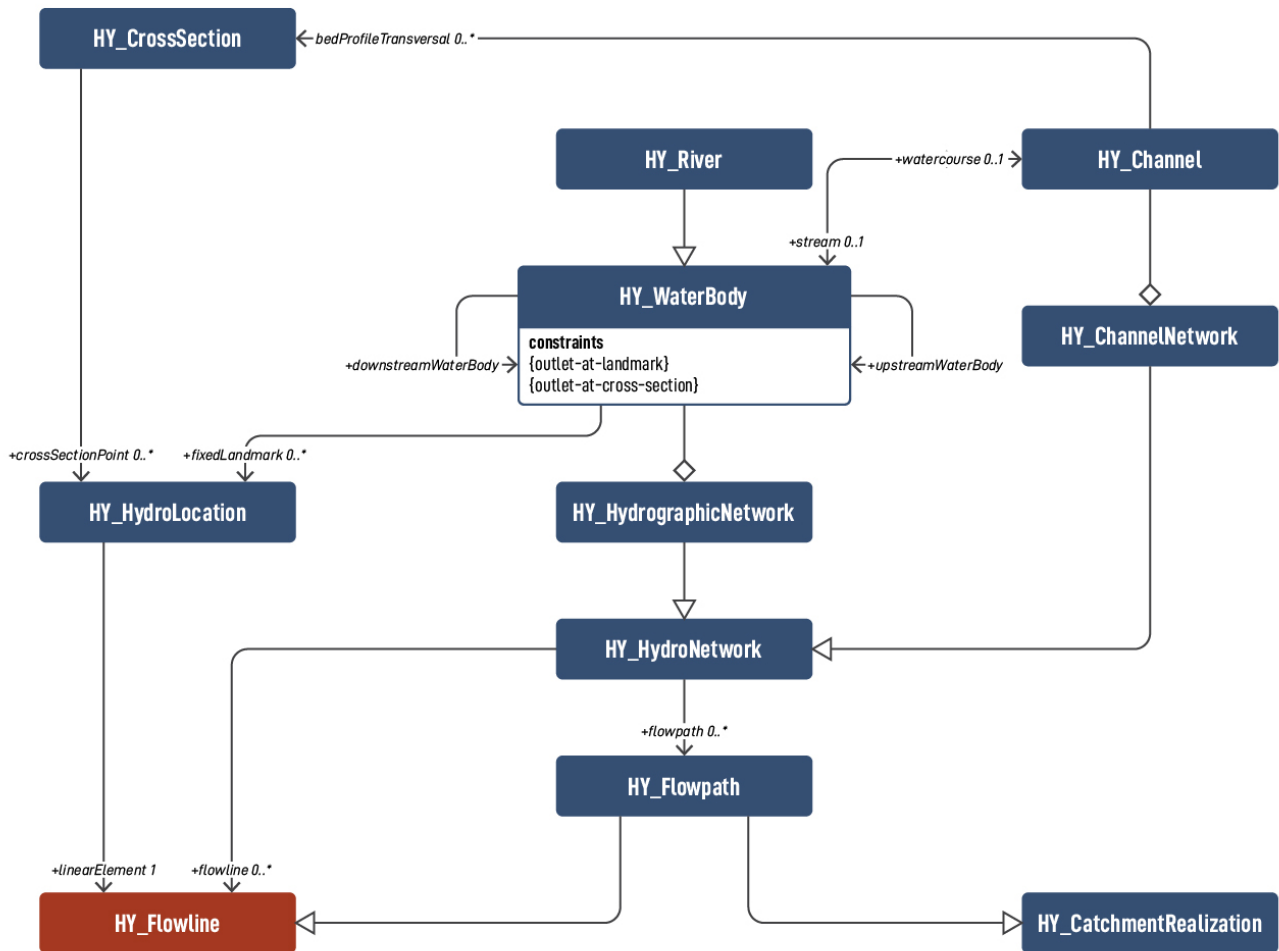


Figure 12. HY\_Features flowline detail. HY\_Flowline, highlighted in red since it is not currently in HY\_Features, is "proposed" by this engineering report and is not currently in HY\_Features.

Figure 13 provides an overview of the river corridor logical data model using color to separate the **rc\_** river corridor logical classes from the **hf\_** hydrofabric classes. Figure 14 shows the relationships between the defined logical classes and the HY\_Features conceptual classes. Notice that, since **hf\_flowpath** is a subclass of **rc\_flowline**, a flowpath will always be a flowline or collection of flowlines but flowlines can form networks of upstream and downstream waterbodies. The distinction between **rc\_flowline** and **rc\_riverReach** is that a flowline will always have a linear representation for use as a linearElement (e.g., hydroLocation addressing) where a riverReach is conceptually a waterbody that may have a polygonal representation.

## River Corridor Logical Classes

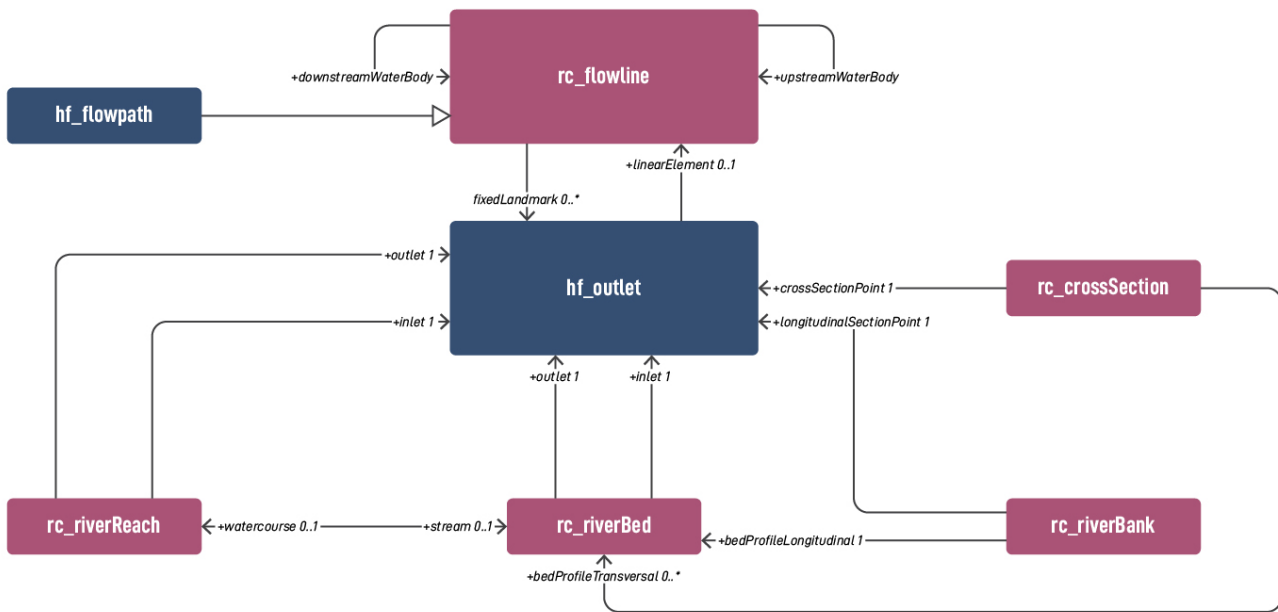


Figure 13. River corridor logical classes in pink with related hydrofabric logical classes in blue.

Figure 14 shows the relationship between HY\_Features concepts and the River Corridor (rc) logical classes. Hydrofabric (hf) logical classes that play a role in the river corridor logical model are included for completeness.

- **rc\_flowline**: Based on the proposed HY\_Flowline concept to allow indirect position along a non-hydrologic linear waterbody representations. Can be the linearElement of an hf\_outlet feature and can reference fixedLandmark hf\_outlet features that lie along the flowline.
- **rc\_crossSection**: Based on the HY\_CrossSection concept of HY\_Features. Can relate to a flowline (which may be a catchment flowpath) through a hf\_outlet feature.
- **rc\_riverBank**: Based on the HY\_LongitudinalSection concept of HY\_Features. Has associations to a riverBed which it characterizes and an hf\_outlet which ties its outlet to the broader flowline (flowpath) network.
- **rc\_riverReach**: Based on the HY\_River concept, a subclass of HY\_Waterbody, is intended to represent a river in one, two, or three dimensions. Building on the "outlet-at-landmark" constraint of HY\_Waterbody, a rc\_riverReach relates to flowlines through an inlet and outlet hf\_outlet feature.
- **rc\_riverBed**: Based on the HY\_Channel concept, relates to rc\_riverReach and provides a reference system for cross sections that do not require the existence of waterbodies. Inherits the "outlet-at-benchmark" constraint from the HY\_Depression concept (which HY\_Channel is a subclass of). This benchmark hydrologic location ties together, flowline, waterbody, and channel. A riverbed feature or set of features, should logically extend to the full extent of a river corridor delineation and be used for the river corridor characterization use case.

### Cross Section Conceptual to Logical Relations

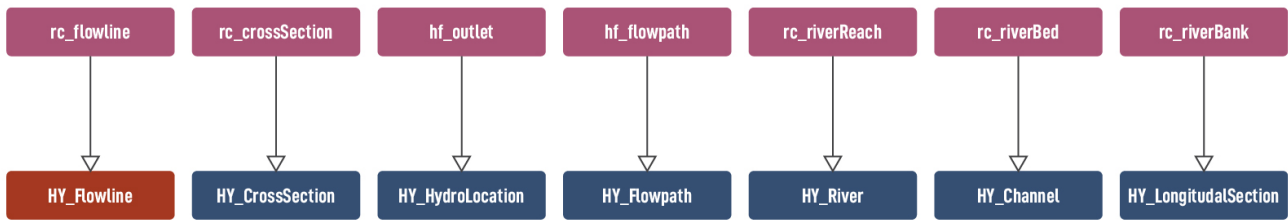


Figure 14. Cross section conceptual to logical model relations represented as class relationships. Logical model classes are pink, existing HY\_Features conceptual classes are blue, and proposed HY\_Features concept is red.

## 8.3. Realization Relations

Figure 15 shows two groups of concepts, position and nexus, and how the hf\_outlet class includes/relates to each. The blue HY\_Features concepts shown can be included in the logical hf\_outlet class. Most directly, hf\_outlet is based on the HY\_HydroLocation concept but can relate to catchments with the contributing and receiving catchment relation of the HY\_Nexus concept. This is based on the idea that the "realization" relationship between nexus and hydroLocation can share some aspects of the nexus concept in a partial inheritance style. A hf\_outlet can also include attributes and associations from the HY\_IndirectPosition concept.

## Realization Relations Including Dropped Classes

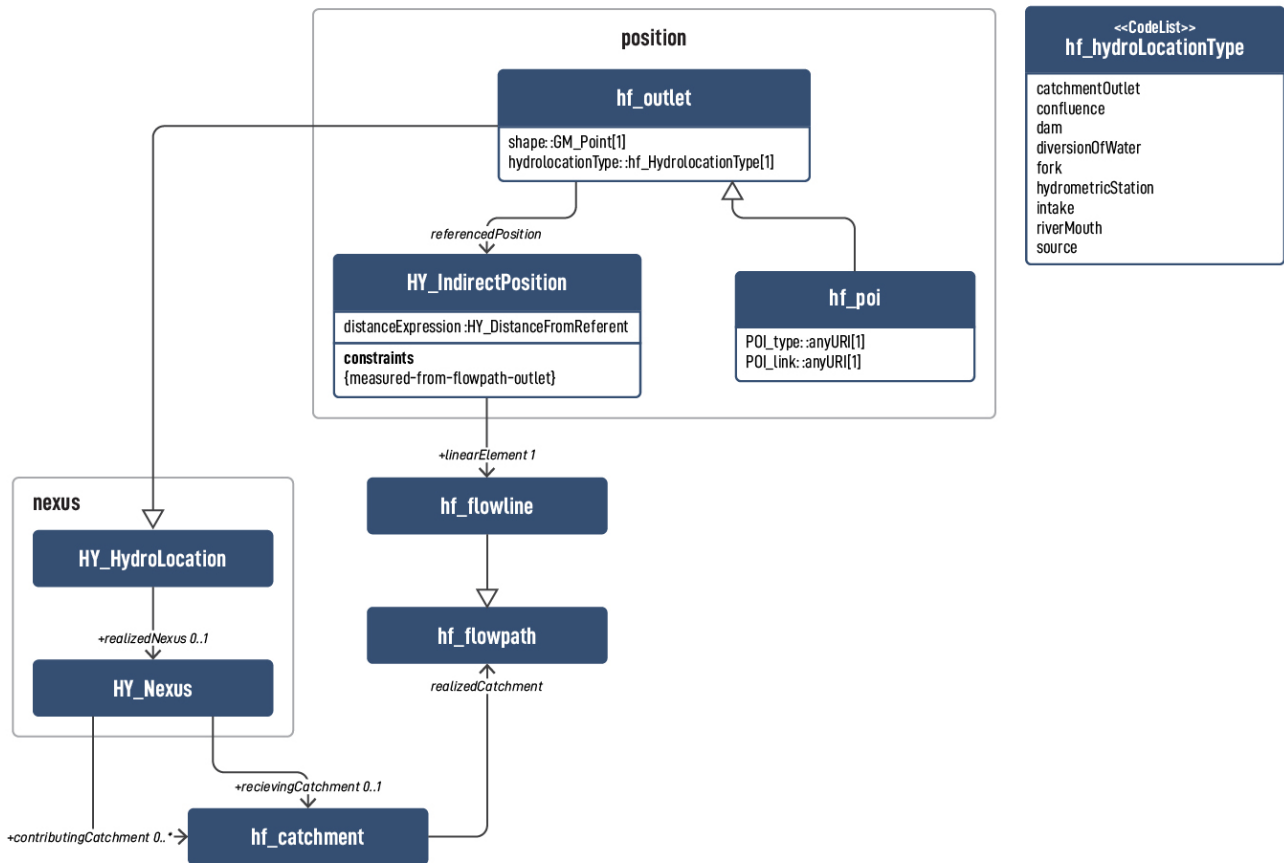


Figure 15. Realization relation showing dropped HY\_Features classes. The `hf_outlet` logical class includes the concepts of the "dropped" HY\_Features classes (`HY_Nexus`, `HY_HydroLocation`, and `HY_IndirectPosition`).

Figure 16 eliminates the HY\_Features concepts that are lumped into `hf_outlet`, showing how the hydrofabric logical model relates outlets to catchments and flowpaths. Similar to `hf_outlet`, the realization relationship between `hf_catchment` and `hf_flowpath` can share some aspects of each through partial inheritance. Formalization of this partial inheritance is left for future work.

## Realization Relations

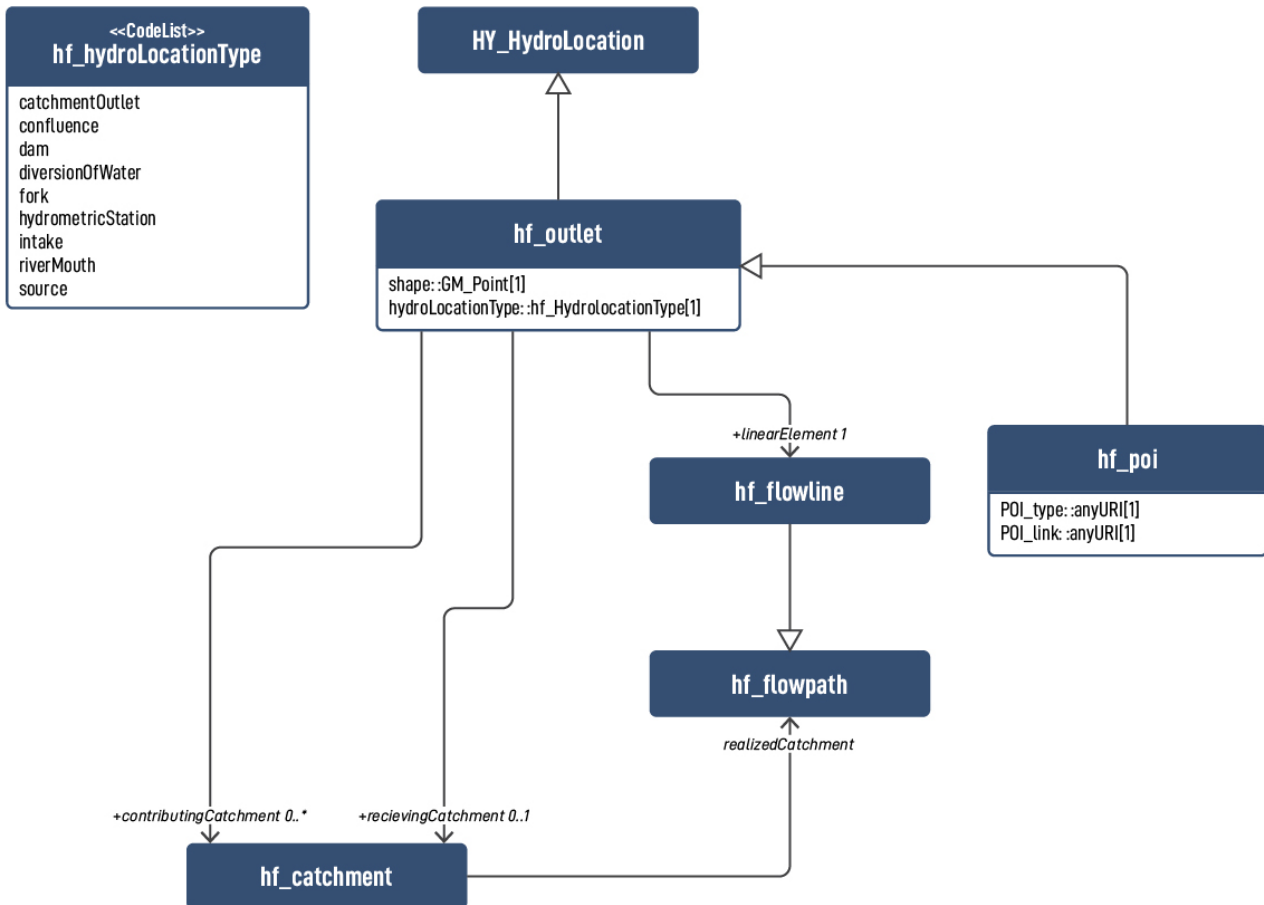


Figure 16. Realization relation.

The logical models presented above represent the outcome of several years of research and development working with the HY\_Features concepts on the use cases described above. It could be used as the basis for standardizing logical and physical data model(s) in the future but will require greater formalization and testing.

# Chapter 9. HY\_Features Change Requests

While HY\_Features was found to be compatible with the needs of the use cases considered here, some key concepts and associations were found to be missing. These are described below:

## 9.1. Realization and Inheritance

In some cases, the logical model developed in the [Use Cases](#) section lumps HY\_Features concepts into single logical classes. The most significant example of this is how the hf\_outlet class includes some concepts from HY\_Nexus, HY\_HydrologicLocation, and HY\_IndirectPosition. Similarly, the hf\_flowpath class can be thought to include some HY\_Catchment concepts as well the HY\_Flowpath catchment realization concept. In both cases, conceptual "hydrologic realization" is involved.

HY\_Features (OGC 16-032r2) includes the following sentence in the definition of "hydrologic realization."

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.

The so-called "sharing" is treated as partial inheritance here. That is, each catchment realization can be thought to inherit certain properties and/or associations from the catchment concept. For example, the flowpath catchment realization can inherit catchment topology but the catchment divide realization does not.

Inclusion of an explicit set of relationships and attributes, perhaps as a simple table, that can be "shared" by the realization relationship would provide important guidance for implementing logical and physical models in accordance with HY\_Features concepts.

## 9.2. Frontal and Inland Sink Nexus Types

HY\_Features includes only one realization of the HY\_Nexus concept, HY\_Hydrolocation. The [Hydrologic Network Connectivity](#) use case found a need for both an internal diffuse outflow and a frontal outflow.

Creation of these additional realizations of the nexus concept would provide a more complete set of hydrologic network termination features. The addition of these two realizations provides a solution for filling in a coverage of catchments where no network exists near a waterbody or in a dry inland area.

## 9.3. Flowline Feature and Linear Referencing

The [Flow Network Location](#) use case illustrates a need further discussed in the [Features](#) and [Topology](#) information summary sections and shown in [Figure 12](#). The existing HY\_Feature concepts do not support indirect positioning along flowing bodies of water that take part in the hydrologic network but are not flowpaths. The solution suggested here (illustrated in [Figure 12](#)) is

inclusion of a HY\_Flowline concept that can be part of a HY\_HydroNetwork and represent a linear representation of any waterbody or channel. HY\_Flowpath would then be treated as a subclass of HY\_Flowline and a subclass of HY\_CatchmentRealization.

## 9.4. Catchment and Hydrogeologic Unit Interface

While not discussed above in detail, the lack of a formal hydrogeologic unit concept in HY\_Features is limiting for [\[Catchment Characterization\]](#) and [River Corridor Characterization](#) applications that are impacted by groundwater. The hydrologic model control volume use case often involves phenomena that involve exchanges with groundwater. Providing an interface class or other means to relate catchment areas and waterbodies to hydrogeologic units would provide clarity on the use of HY\_Features for this use case.

# Appendix A: PlantUML Source for Logical Model

## A.1. Conceptual to logical model relations

```
@startuml
title Conceptual to logical model relations
class HY_Catchment
class HY_Flowpath
class HY_CatchmentDivide
class HY_HydroNetwork
class HY_HydroLocation
class hf_Catchment
class hf_Flowpath
class hf_Divide
class hf_lookup
class hf_POI
class hf_outlet
hf_Catchment --|> HY_Catchment
hf_Flowpath --|> HY_Flowpath
hf_Divide --|> HY_CatchmentDivide
hf_lookup --|> HY_HydroNetwork
hf_POI --|> HY_HydroLocation
hf_POI --|> hf_outlet
HY_HydroLocation --> "realizedNexus" HY_Nexus
hf_frontalOutflow --> "realizedNexus" HY_Nexus
hf_internalDrain --> "realizedNexus" HY_Nexus
@enduml
```

## A.2. Cross Section Conceptual to Logical relations

```
@startuml
title Cross Section Conceptual to Logical relations
class rc_flowline #tan
class rc_crossSection #tan
class hf_outlet #tan
class hf_flowpath #tan
class rc_riverReach #tan
class rc_riverbed #tan

rc_flowline --|> HY_Flowline
rc_crossSection --|> HY_CrossSection
rc_riverBank --|> HY_LongitudinalSection
rc_riverReach --|> HY_River
rc_riverbed --|> HY_Channel

hf_outlet --|> HY_HydroLocation
hf_flowpath --|> HY_Flowpath

class HY_Flowline #cyan

@enduml
```

### A.3. HY\_Features Flowline Detail

```

@startuml
title HY_Features Flowline Detail

class HY_Flowline #cyan

HY_WaterBody --o HY_HydrographicNetwork
HY_WaterBody --> "fixedLandmark 0..*" HY_HydroLocation

HY_Channel --o HY_ChannelNetwork
HY_HydrographicNetwork --|> HY_HydroNetwork
HY_ChannelNetwork --|> HY_HydroNetwork
HY_HydroNetwork --> "+flowpath 0..*" HY_Flowpath
HY_HydroNetwork --> "+flowline 0..*" HY_Flowline

HY_River --|> HY_WaterBody
HY_Flowpath --|> HY_Flowline
HY_Flowpath --|> HY_CatchmentRealization

HY_CrossSection "bedProfileTransversal 0..*" <-- HY_Channel
HY_Channel "+watercourse 0..1" <--> "+stream 0..1" HY_WaterBody

HY_WaterBody --> "+downstreamWaterBody" HY_WaterBody
HY_WaterBody --> "+upstreamWaterBody" HY_WaterBody

class HY_WaterBody {
---
constraints
{outlet-at-landmark}
{outlet-at-cross-section}
}

HY_HydroLocation --> "+linearElement 1" HY_Flowline

HY_CrossSection --> "+crossSectionPoint 0..*" HY_HydroLocation

@enduml

```

## A.4. Hydrofabric Logical Classes

```

@startuml
title Hydrofabric Logical Classes
class hf_Catchment {
type
mainstem
}
hf_Catchment --> "+lowerCatchment 0..1" hf_Catchment
hf_Catchment --> "+outflow 0..1" hf_outlet
hf_outlet <|-- hf_POI
class hf_Flowpath {
lengthkm
}
hf_Flowpath --> "+realizedCatchment 1" hf_Catchment
class hf_Divide {
areasqkm
}
hf_Divide --> "+realizedCatchment 1" hf_Catchment
class hf_lookup
hf_lookup --> "+realizedCatchment 1" hf_Catchment
hf_lookup --> "+catchmentDivide 1..*" hf_Divide
hf_lookup --> "+flowpath 1..*" hf_Flowpath

class hf_outlet
hf_outlet --> "+linearElement 1" hf_Flowpath
hf_outlet --> "+contributingCatchment 0..*" hf_Catchment
hf_outlet --> "+recievingCatchment 0..1" hf_Catchment

class hf_POI {
POI type
POI link
}

class hf_frontalOutflow
hf_frontalOutflow "+outflow 0..1" <-- hf_Catchment
class hf_internalDrain
hf_internalDrain "+outflow 0..1" <-- hf_Catchment
@enduml

```

## A.5. Realization relations including dropped classes

```

@startuml
title Realization relations including dropped classes

package position <<Rectangle>> {
class HY_IndirectPosition #tan {
+ distanceExpression :HY_DistanceFromReferent
---
constraints

```

```

{measured-from-flowpath-outlet}
}

class hf_outlet {
+ shape: :GM_Point[1]
+ hydrolocationType: :hf_HydrolocationType[1]
}
class hf_POI {
+POI_type: :anyURI[1]
+POI_link: :anyURI[1]
}
}

package nexus <<rectangle>> {
class HY_Nexus #tan
class HY_HydroLocation #tan
}

hf_Flowpath "realizedCatchment" <-- hf_Catchment
class hf_HydrolocationType <<CodeList>> {
catchmentOutlet
confluence
dam
diversionOfWater
fork
hydrometricStation
intake
riverMouth
source
}
hf_outlet --|> HY_HydroLocation

HY_HydroLocation --> "+realizedNexus 0..1" HY_Nexus

hf_outlet <|-- hf_POI

hf_outlet --> "referencedPosition" HY_IndirectPosition

hf_Flowline --|> hf_Flowpath

HY_IndirectPosition --> "+linearElement 1" hf_Flowline

HY_Nexus --> "+contributingCatchment 0..*" hf_Catchment
HY_Nexus --> "+recievingCatchment 0..1" hf_Catchment
@enduml

```

## A.6. Realization relations

```

@startuml
title Realization relations

hf_Flowpath "realizedCatchment" <-- hf_Catchment
class hf_HydrolocationType <<CodeList>> {
catchmentOutlet
confluence
dam
diversionOfWater
fork
hydrometricStation
intake
riverMouth
source
}

HY_HydroLocation <|-- hf_outlet

class hf_outlet {
+ shape: :GM_Point[1]
+ hydrolocationType: :hf_HydrolocationType[1]
}
hf_outlet --> "+linearElement 1" hf_Flowline

hf_Flowline --|> hf_Flowpath

hf_outlet --> "+contributingCatchment 0..*" hf_Catchment
hf_outlet --> "+recievingCatchment 0..1" hf_Catchment

hf_outlet <|-- hf_POI

class hf_POI {
+POI_type: :anyURI[1]
+POI_link: :anyURI[1]
}

@enduml

```

## A.7. River Corridor Logical Classes

```

@startuml
title River Corridor Logical Classes
skinparam nodesep 100
skinparam ranksep 100
class rc_flowline
class rc_crossSection
class hf_outlet
class hf_flowpath
class rc_flowline
class rc_riverbed

hf_flowpath -|> rc_flowline

hf_outlet --> "+linearElement 0..1" rc_flowline

hf_outlet "+crossSectionPoint 1" <- rc_crossSection
rc_riverBank -> "+longitudinalSectionPoint 1" hf_outlet

rc_riverbed "+bedProfileLongitudinal 1" <- rc_riverBank

rc_crossSection -> "+bedProfileTransversal 0..*" rc_riverbed

rc_riverreach "+watercourse 0..1" <-> "+stream 0..1" rc_riverbed

hf_outlet "+outlet 1" <-- rc_riverbed
hf_outlet "+inlet 1" <-- rc_riverbed

hf_outlet "+outlet 1" <-- rc_riverreach
hf_outlet "+inlet 1" <-- rc_riverreach

rc_flowline --> "fixedLandmark 0..*" hf_outlet

rc_flowline --> "+downstreamWaterBody" rc_flowline
rc_flowline --> "+upstreamWaterBody" rc_flowline
@enduml

```

# Appendix B: Revision History

Table 1. Revision History

<b>Date</b>	<b>Editor</b>	<b>Release</b>	<b>Primary clauses modified</b>	<b>Descriptions</b>
September 7, 2022	D. Blodgett	.1	all	initial version
September 8, 2022	J.M. Johnson	.2	all	edit and added sections
September 9, 2022	D. Blodgett	.3	all	reconcile edits and add contributions from M. Wernimont and J. Leroy.
September 13, 2022	D. Blodgett	.4	all	reconcile edits from A. Bock.

# Appendix C: Bibliography

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