Ministry of Agriculture and Lands
Crown Registry and Geographic Base

Freshwater Atlas v1.3

Fundamental Watersheds (FW)

Technical Specification

Prepared for

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THE GEOSPATIAL EXPERTS

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1 REVISION HISTORY

Date	Version	Author	Description of Changes
May 7, 2008	0.1	Refractions Research	Initial Fundamental Watershed creation rules.
May 30, 3008	0.2	Refractions Research	Addition of rules and processing for subdividing waterbody fundamental watershed polygons. Addition of order/magnitude assignment rules.
June 11, 2008	0.3	Refractions Research	Modified classic order and magnitude assignment rule to assign 0 to face units (that flow into the ocean).

2 INTRODUCTION

The concept of Fundamental Watershed polygons has been developed to deal with limitations imposed by the previous method of creating Freshwater Atlas watershed polygons. These limitations were:

- Watershed polygons along double-line rivers included the “face unit” drainage areas along the banks of the rivers. This created “long skinny” watershed polygons, which did not adequately subdivide the land area along the rivers. This also did not fully distinguish land from river area.

- Confluences between single-line rivers were not fully subdivided into watersheds for all stream edges meeting at the confluence. Specifically, the mainstem stream did not have a watershed boundary dividing its upstream and downstream portions. This prevented attributes for the upstream watershed from being computed.

The definition of Fundamental Watersheds addresses both of these issues by incorporating additional watershed boundary edges. The additional edges provide a more useful subdivision of the land area, and fully separate land from water.

Furthermore, Fundamental Watershed polygons are provided with a new Local Watershed Code attribute, in addition to their basic Watershed Code attribute. The Local Watershed Code gives each watershed polygon an ordering along the route from which it obtains its basic watershed code. This provides a more fine-grained hierarchy of watershed polygons. The Local Watershed Code is essentially defined as the Watershed Code of the most downstream tributary adjacent to the watershed polygon.

The goal of defining Fundamental Watersheds is to provide a subdivision of the provincial land area which is at an appropriate scale for use in applications. Also, by providing the Local Watershed Code it should be possible to aggregate watersheds to any level in the watershed hierarchy by using only scalar attribute queries (i.e. with no complex spatial or hierarchical querying). It is hoped that Fundamental Watersheds will become the de-facto base watershed layer used by end users.

3 RULES

This section describes the rules which govern the creation of the Fundamental Watershed dataset. They are intended to capture in a precise, but non-algorithmic way the definition of this dataset. The rules are prescriptive, and do not specify the precise process of forming the watershed polygons from the base unit polygons.

3.1 FUNDAMENTAL WATERSHED POLYGONS

Fundamental watersheds are defined by the following rules.

- Waterbody (lake, river, and canal) banks are used to close off face units from the adjacent waterbody.
- Waterbodies that are completely contained in a single watershed polygon (i.e. in-line or isolated lakes, and in-line rivers) are merged with the surrounding watershed polygon (which thus does not contain holes for the contained waterbody). However, if a waterbody contains an island which itself contains watersheds (e.g. which contains stream edges) then those watersheds are retained (and will thus form holes in the containing watershed polygon).
- Islands in double-line rivers that do not have watersheds on them are dissolved into their containing river polygon. In a braided double-lined river system this essentially creates a “flood plain polygon” extending to the bank edges of the outermost double-line side channels.
- Adjacent watershed polygons that do not contain an observed primary flow are dissolved together, grouped on identical watershed codes.
- Watershed polygons that are bounded by double-line rivers or lakes are split at group code boundaries.
- Fundamental watershed waterbody polygons are further subdivided using the centerline skeleton of the waterbody and any connector skeleton edges that have a stream order greater than 1.

3.2 LOCAL WATERSHED CODE

Each Fundamental Watershed polygon is assigned a *local_code* attribute. The rules defining the value of the attributes are:

- In general, the *local_code* of a Fundamental Watershed polygon is equal to the *ws_code* of the most downstream tributary that the fundamental watershed polygon touches.
- The *local_code* and *ws_code* attribute of watersheds at river mouths (i.e. watersheds containing the mouth of a single-lined stream as well as both watersheds on either side of a double-lined river mouth) are the same.

4 APPROACH

The basis of the fundamental watersheds is the Freshwater Atlas Unit Watershed polygonal coverage. This is a polygonal coverage dataset derived directly from the generated Height-of-Land lines produced by the WaterBug Watershed Boundary Generator software. The unit polygon coverage is very fine-grained, with many small polygons.

Fundamental Watersheds are formed as aggregations of base unit polygons. The processing steps detailed in section 5.2 describe how these unit polygons are aggregated and subsequently subdivided to maintain the rules outlined in section 3.1. The resultant polygonal coverage contains larger polygonal areas than the base unit polygonal coverage, which is more efficient and amenable for use in business applications.

5 PROCESSING

This section describes in detail the technical aspects of the processing carried out to generate the Fundamental Watershed dataset.

5.1 INPUT / OUTPUT

The Fundamental Watershed generation and attribution software require as input:

- Unit watersheds polygons with the following attributes:
  - *ws_id* - a unique identifier
  - *non-isolated_route_id* - a route identifier that merges isolated unit watersheds to adjacent non-isolated watersheds
  - *wb_id* - the unique waterbody identifier if the unit watershed polygon is water
- A list of hydrographic and height-of-land edges that bound every unit polygon
- A list of hydrographic network edges contained within every unit polygon
- The Freshwater Atlas stream network complete with a *ws_code* attribute

The output of the fundamental processing yields:

- Fundamental watersheds, complete with a watershed code and a local watershed code attribute

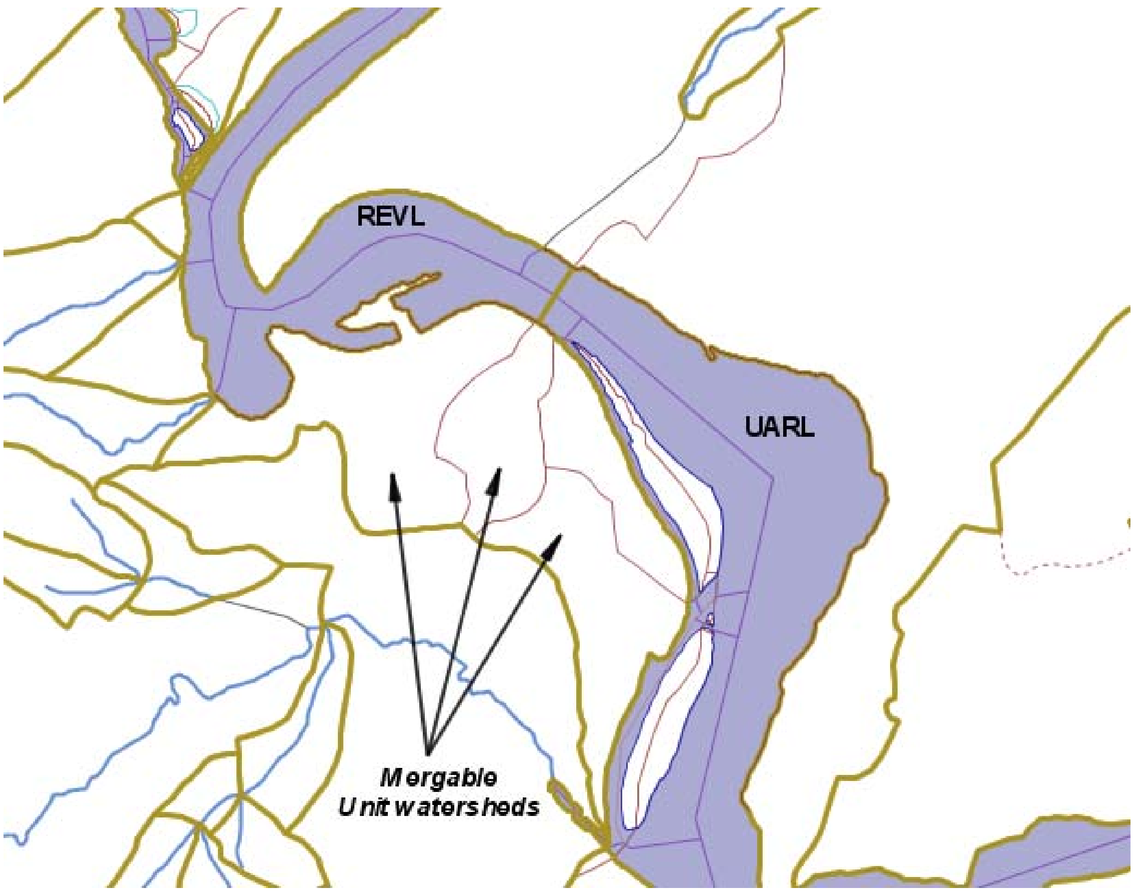
5.2 PROCESSING STEPS

5.2.1 Generate Fundamental Polygons

Fundamental watersheds are an aggregate of unit watershed polygons, grouped together on certain attributes. The following steps describe the attributes assigned to unit watershed polygons that yield the desired aggregated result.

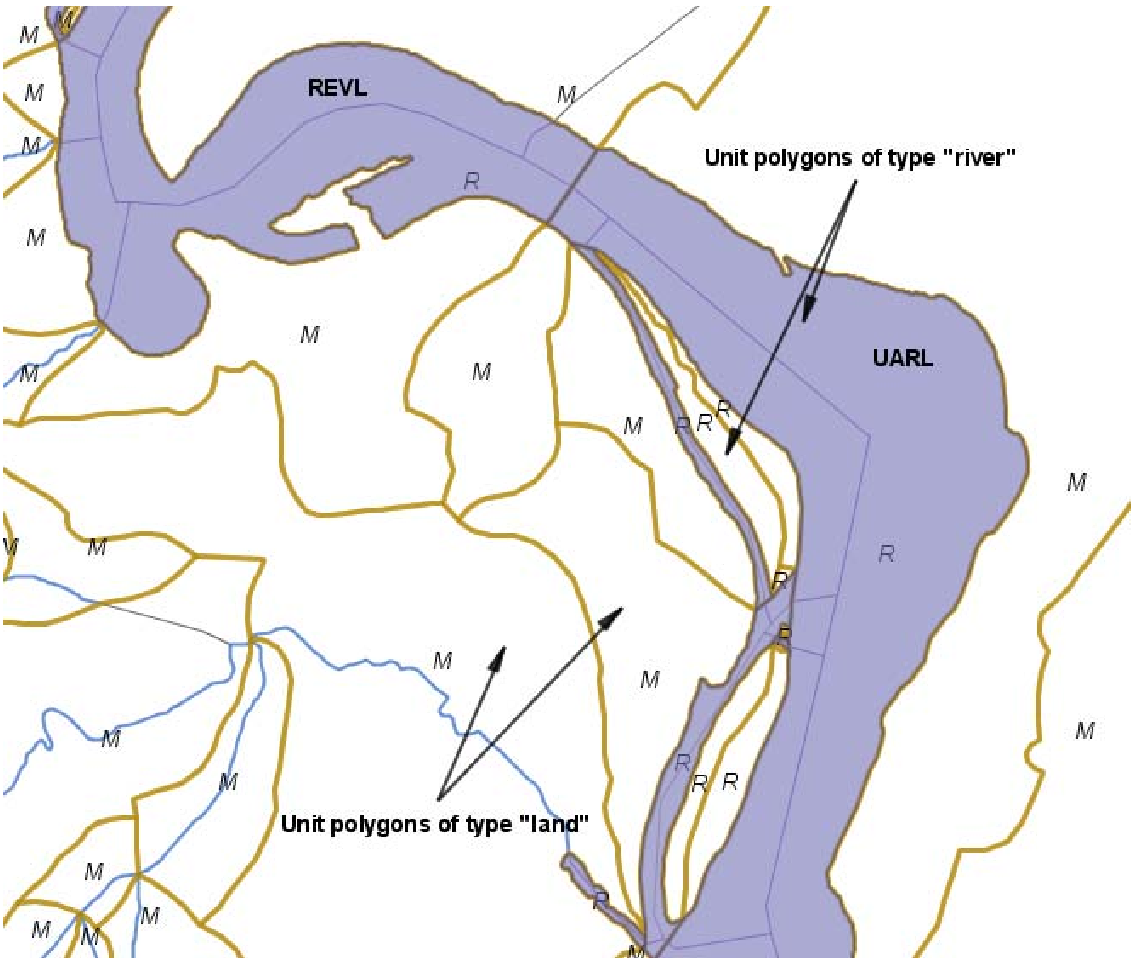
1. Compute an *is_mergable* attribute

    This step determines if a unit polygon is possibly mergable with adjacent unit polygons. A watershed unit polygon is flagged as mergable if it does not contain any primary observed flows through it (edge codes 1000, 1050, 2000).



2. Compute a *type* attribute

This step attributes unit polygons to the type of area they represent. Possible values are 'R', 'L', 'r', 'l', and 'M', representing a river, lake, manmade river, manmade lake or land respectively. Unit watersheds of different types are not dissolved together. As a result, river and lake banks may be used to define the boundary of fundamental watersheds. Subsequent processing determines which banks are excluded from the fundamental boundary-defining set of edges (such as in-line river or lake banks, or river banks in a braided river network).



3. Assign a *ws_code* attribute

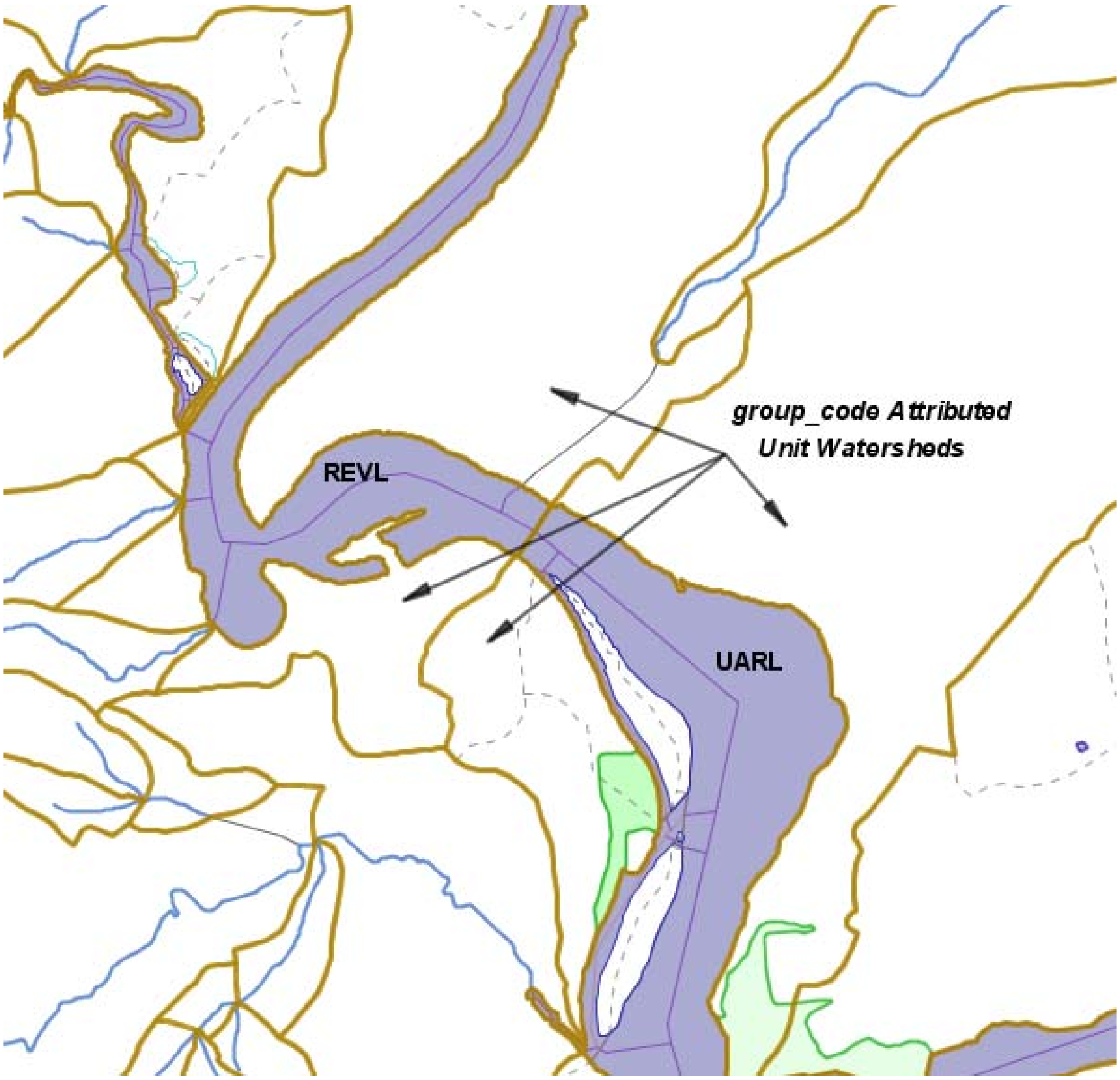
   Every unit polygon receives the *ws_code* of the non-isolated route it is associated with. Adjacent unit watersheds of different watershed codes are not dissolved together. This ensures that the traditional or “classical” watersheds can still be generated from the fundamental watershed coverage. If there is a conflict with multiple watershed codes in a polygon, ignore any 1200 or 1400 edges causing the conflict. If there are only 1200 or 1400 edges within a polygon causing a conflict, this is an error and must be resolved.

4. Compute an *island_id* attribute and update the *type* attribute

   Every unit watershed that is contained within an island receives the island’s unique identifier. Additionally, every unit watershed on an island receives the *area_type* of the waterbody the island is contained within. In particular, all unit watersheds on an island that is on a lake receive either ‘L’ or ‘l’, depending on the type of lake the island is on. All unit watersheds on a river island receive either ‘R’ or ‘r’, depending on the type of river. If an island is bounded by both a river and a lake, the river takes precedence and the unit watersheds on the island receive a type of ‘R’ or ‘r’. In subsequent processing, islands that do not have any watersheds already on them are excluded from the fundamental boundary-defining set of edges. Thus, some unit watersheds (i.e. islands in a braided river network), are not attributed as land and are possibly dissolved into the waterbody that surrounds it.

5. Compute a *group_code* attribute

Every unit watershed that borders a lake or river that also spans a group code boundary is attributed with the group code of the waterbody it drains into. This ensures that unit watersheds are not aggregated across watershed group boundaries.



6. Create a fundamental boundary-defining set of edges

   Using the attributes applied in prior steps, boundaries of unit watershed polygons are either discarded or retained in the use of building fundamental watersheds. Unit watershed boundary edges are retained wherever adjacent unit watershed attributes differ (i.e., where watershed codes, area types, or group codes are not equivalent).

7. Remove in-line waterbodies from the boundary-defining set of edges

   In-line waterbodies – waterbodies that don't have any watershed lines touching them – are subtracted from the fundamental boundary-defining set of edges.

8. Polygonize fundamental watersheds

   Using the fundamental boundary-defining set of edges and a transitive closure technique, a fundamental - unit watershed relationship table is constructed. Based on these relationships, fundamental watersheds are built from all the collected edges of the contained unit watershed polygons.

5.2.2 Assignment of Local Watershed Codes

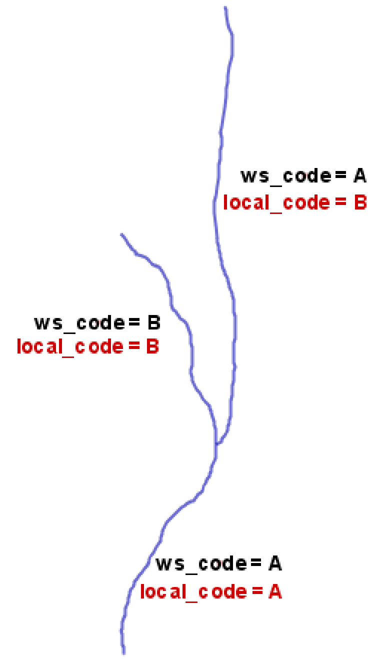
After fundamental watersheds have been created, they are attributed with a new *local_code* attribute. The intent of this attribute is to place the watershed in a hierarchical order within its own watershed code. The *local_code* is defined to be the *watershed_code* of the most downstream tributary the watershed touches. The exception to this rule occurs at double-lined river mouths, where the *local_code* of the river is transferred to the watersheds on either side of the river banks. In this manner, the first two watersheds upstream of a river mouth can be sorted with respect to each other.

The following processing steps outline how the *local_code* attribute is computed and applied to fundamental watersheds:

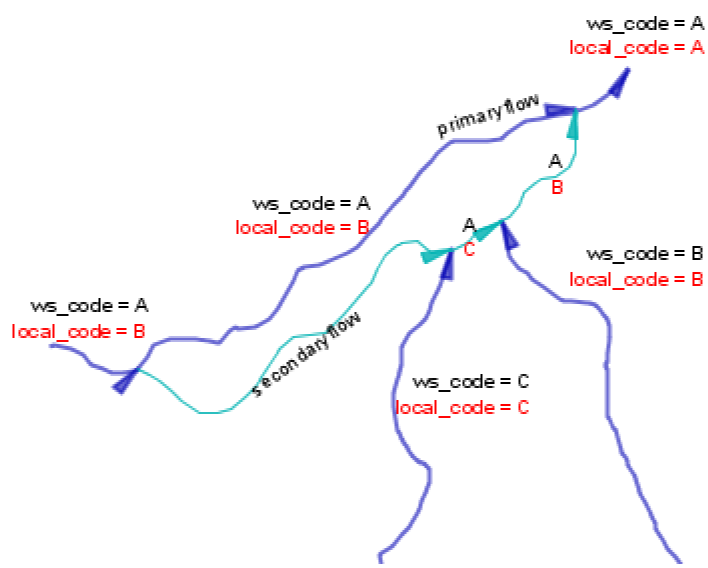
1. Attribute the stream network with a *local_code* attribute.

    a. A stream network is created and at every degree-3 confluence point of 2 input and 1 output stream arcs, the local watershed code is computed and attributed to the 2 input stream arcs.

    b. Whenever the 2 input stream arcs are both primary, the main route receives the watershed code of the tributary and the tributary receives its own watershed code as the local code.



    c. Wherever a primary stream edge flows into a secondary edge, side channel edges are traversed downstream until reaching a primary flow edge, and this point is considered the confluence. The minimum local watershed code is then applied to every secondary flow edge traversed.



d. All degree-2 confluences in the primary network are then processed and the local code attribute is pushed upstream.

2. The local watershed code is attributed to fundamental watersheds in the following order.

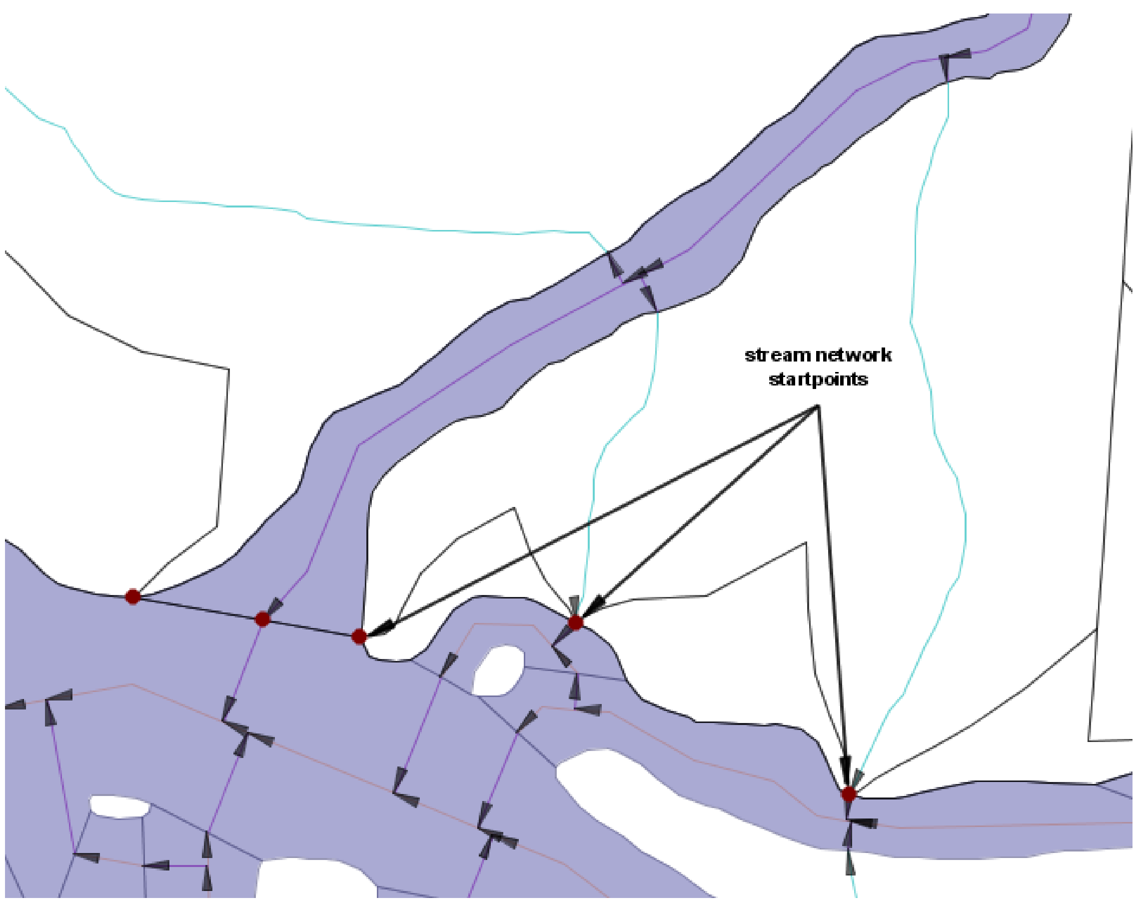
   a. Every watershed that contains at least one primary edge of the processed stream network receives the minimum local code assigned to the edges within that polygon.

   b. Stream network start points are identified. This includes:

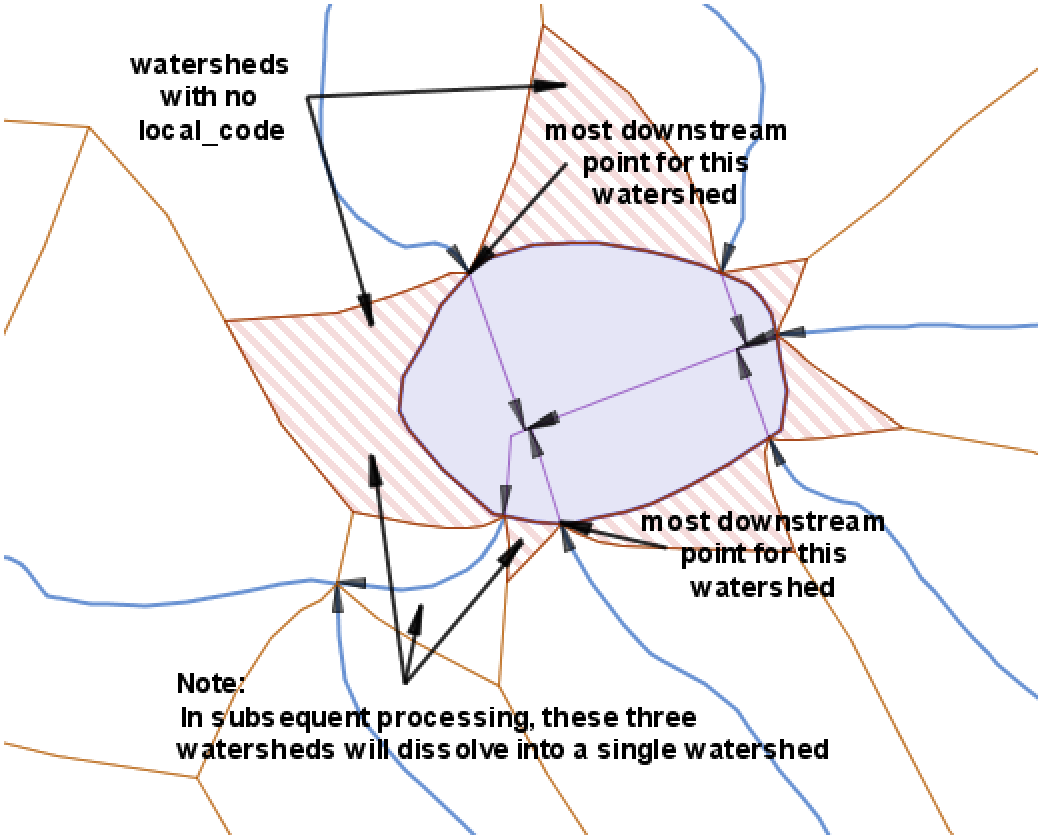
      i. Start points of all primary network flows

      ii. Delimiters at double-lined river confluences

      iii. Secondary flows that enter a waterbody of a different watershed code.



c. Watersheds that don't have a primary flow in them are attributed with the minimum local code of the identified network start-points they touch.



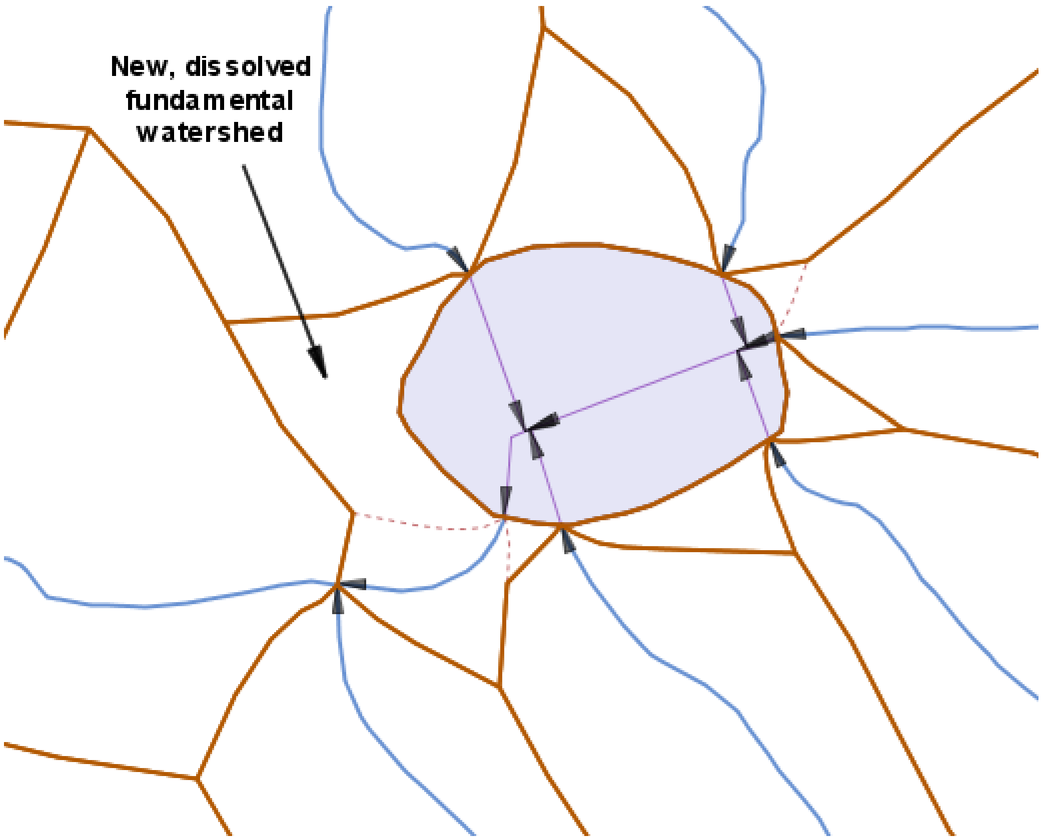
d. Remaining watersheds that do not yet have an assigned local code receive the minimum (most downstream) local code of the adjacent fundamental watersheds with a greater (upstream) watershed code.

e. Remaining watersheds that do not yet have an assigned local code receive the minimum local code of the adjacent fundamental watersheds with the same watershed code.

f. Remaining watersheds that do not yet have an assigned local code receive the value of their watershed code. This is the common case for isolated fundamental watersheds or coastal islands that do not have any flow on them.

5.2.3 Dissolve Fundamental Watersheds

Once fundamental watersheds have been defined and appropriately attributed with a watershed code and a local watershed code, a dissolve is applied to the dataset. Adjacent watersheds with the same attributes (in particular, *ws_code*, *local_code*, and *area_type*) are grouped together and dissolved, keeping the distinction between land and water.



5.2.4 Subdivide Fundamental Watershed Waterbody Polygons

At this stage fundamental polygons exist for the provincial dataset, however large double line rivers and lakes still remain as single large polygons. This step subdivides these waterbody polygons into smaller fundamental watershed polygons using the following processing steps.

1. For each fundamental watershed polygon of type ‘X’, ‘R’, or ‘L’:

    a. Select all centerline flow edges (1200, 1300, 1250 and 1475) contained within the polygon

b. Select all secondary flow edges (1350) and connector edges (1450) that have a local watershed code (See Section 5.2.2), are contained within the selected polygon, and have an order greater than 1.

c. Create polygons from the selected edges and the edges bounding the fundamental watershed waterbody polygon. Dangling 1450s or other edges are ignored in this process.

d. Populate the local watershed code of the polygons formed above (step c) using the most downstream local code assigned to the network arcs bounding the polygons in this order:

   i. 1200 or 1250 network edges; if one of these does not exist then

   ii. 1300 or 1350 network edges; if one of these does not exist then

   iii. 1475 (lake arm) network edges;

e. In some cases split polygons will not be assigned local codes. In these cases if the entire waterbody polygon is contained within a single fundamental watershed polygon it is merged with the surrounding polygon. If there are multiple surrounding fundamental watershed polygons the waterbody fundamental watershed polygons will remain as is (unsplit) and will retain the local code originally assigned to it.

f. Populate the watershed code and waterbody key of the polygons formed above that were assigned a local watershed code from the watershed code and waterbody key of the waterbody they are contained in.

g. Assign type of ‘X’ or ‘R’ or ‘L’, depending on the type of fundamental watershed polygon being divided. (*Polygons that were not assigned a local watershed code and were merged with the land around them will have type = null (land).*)

h. Dissolve adjoining polygons where the watershed code, local watershed code and type attributes are the same. Do not dissolve across 1200, 1250, 1300 network edges. It is okay to dissolve across 1475, 1450, and 1350. This will reduce the number of polygons and make the waterbody fundamental watershed polygons follow the same rules as the land based fundamental watersheds.

5.2.4.1 Issues

One of the goals of the rules defined above was to ensure that each watershed waterbody polygon touched a bank or delimiter edge of a waterbody. However, for some fundamental watershed waterbody polygons the rules do not accomplish this goal. For the province there are approximately 30 such polygons where this occurs.

The fundamental watershed waterbody polygons that do not touch a bank edge are polygons that are formed around a lake arm and which also meet one of the following criteria:

1. **The lake arm has only order 1 streams flowing into it.**

   In the following figure the two green polygons receive the local code of the lake output 1200 flow arc. The orange polygon formed by the lake arm gets the local code of the most downstream order 1 stream that flows into the lake arm. As a result, the fundamental watershed waterbody polygon formed by the lake arm does not get merged with an outer polygon and does not touch a bank edge.

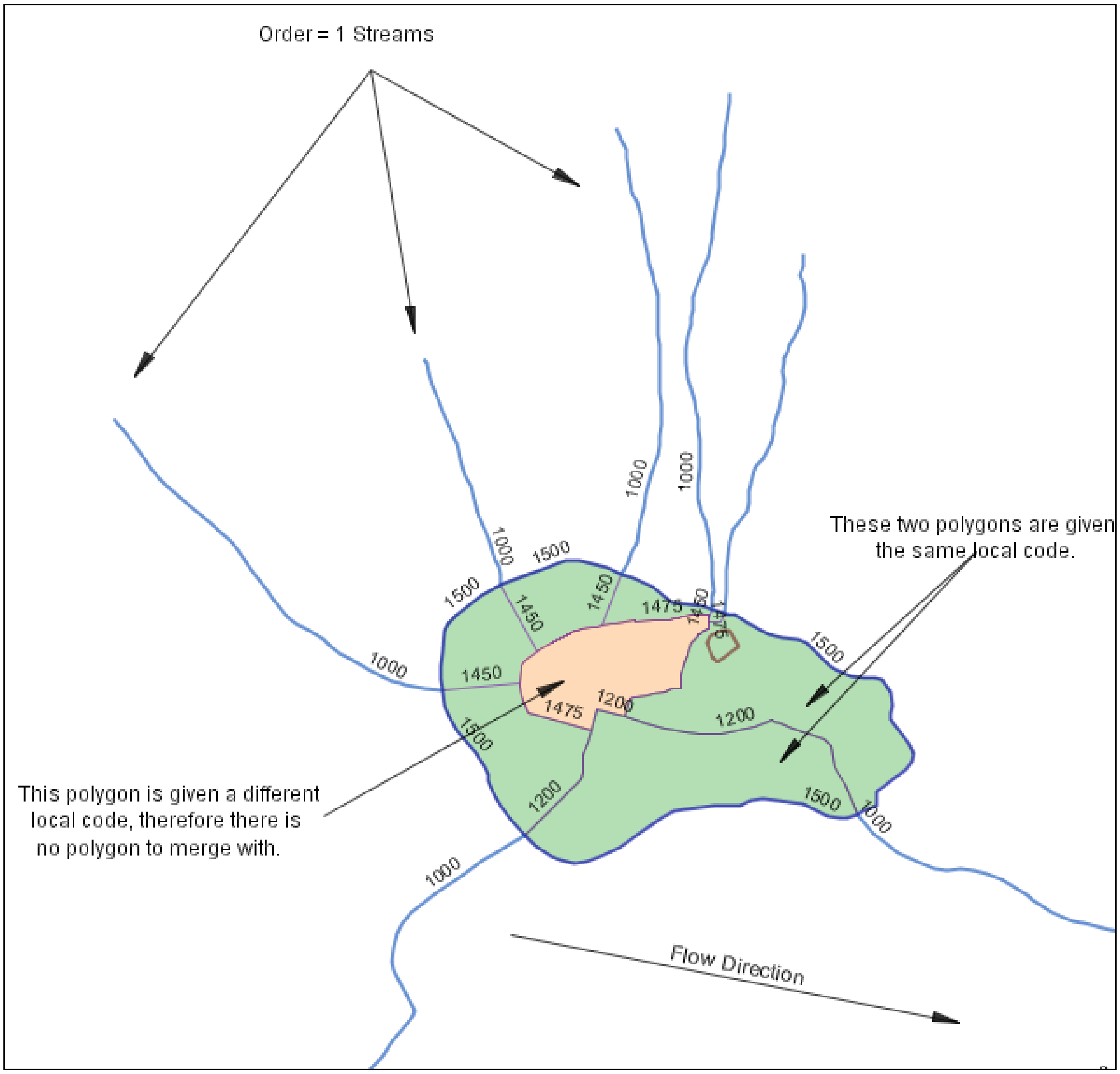


Figure 1: TURN (1549800, 798795)

2. **There are streams flowing into the centerline of the lake between the exit and entry of the lake arm.**

   In the following figure the polygon formed by the lake arm (pink polygon) receives the local code from the most downstream tributary to either the lake arm or lake center line arc between the lake arm exit and entry points. No other waterbody fundamental watershed polygons receive this local code; therefore there is no polygon to merge the lake arm polygon with and this polygon does not touch any bank edges.

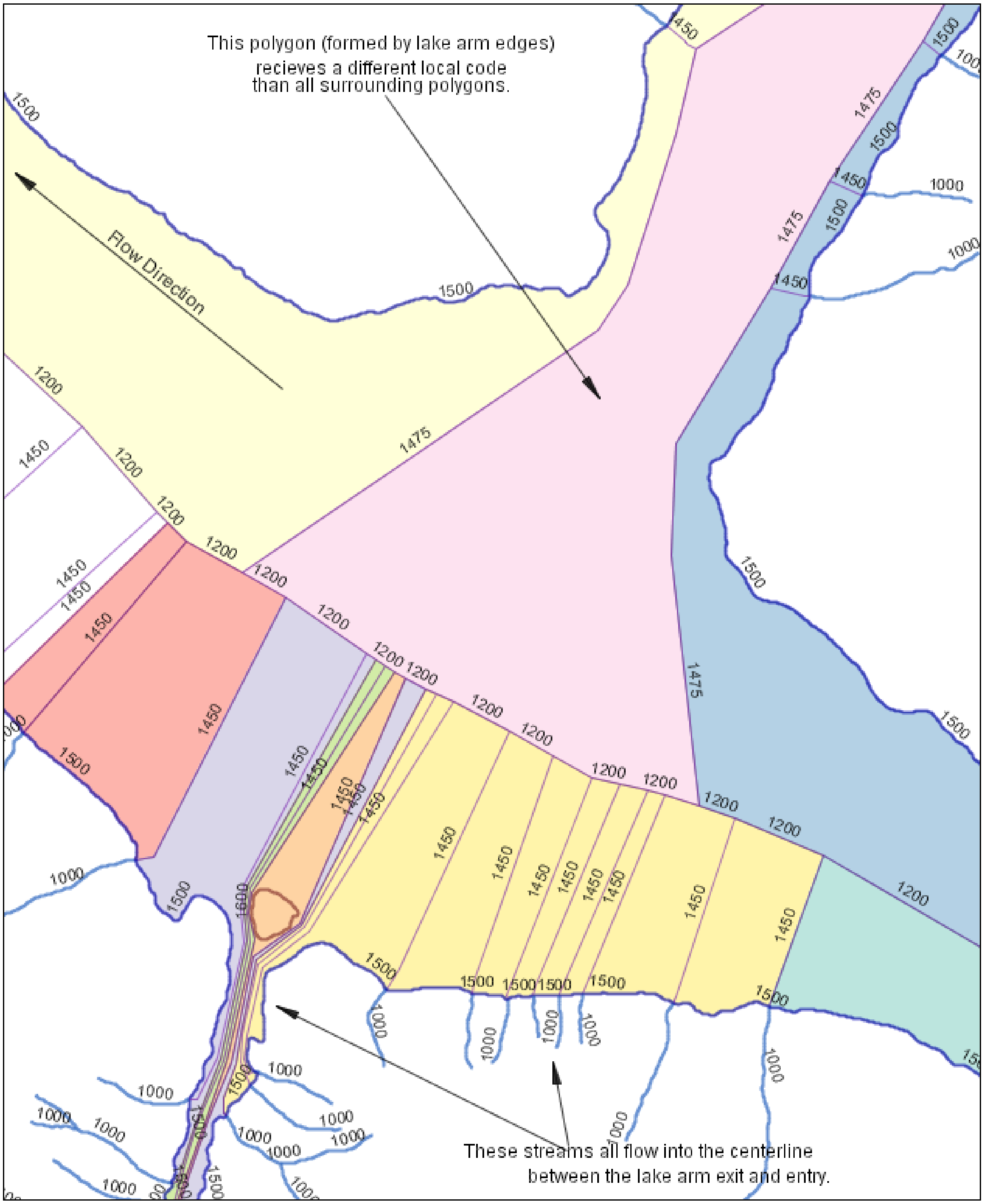


Figure 2: CLRH (1549800, 798795)

6 FUNDAMENTAL WATERSHED ORDER AND MAGNITUDE ASSIGNMENT

6.1 INTRODUCTION

The new Fundamental Watersheds being created for version 1.3 and subsequent releases of the Freshwater Atlas will require that a classic and local order and magnitude be assigned to each fundamental watershed polygon.

6.2 CLASSIC ORDER AND MAGNITUDE

The classic order and magnitude attributes should be assigned in keeping with the rules used to assign order and magnitude to the "classic" watersheds. Classic order and magnitude is defined as the largest magnitude and associated order of the watershed code assigned to the fundamental watershed polygon. Fundamental watershed polygons that do not contain a stream edge or are not bounded by a waterbody bank (face units that flow directly into the ocean) receive a "classic" order and magnitude of zero (0).

The population of the classic order and magnitude attributes on fundamental watershed polygons allow for the formation of the "classic" watersheds by dissolving on watershed code, order, and magnitude.

6.3 LOCAL ORDER AND MAGNITUDE

The computation of local order and magnitude is more complex than that of classic order and magnitude. The local order and magnitude should reflect the order and magnitude of the fundamental watershed polygon's location in the stream network. This is in keeping with the local watershed code that allows the fundamental watersheds to be located on the stream network.

In the general case, local order and magnitude for the fundamental watershed polygon should be the largest magnitude and associated order of a contained flow edge with the same watershed code (NOT local watershed code) as the fundamental watershed polygon. This will reflect the order and magnitude of the fundamental watershed polygon at that location in the stream network.

For waterbody fundamental watershed polygons, the local order and magnitude should be the largest magnitude and associated order of a bounding flow edge with the same watershed code as the fundamental watershed polygon. This reflects the order and magnitude of the water contained within the waterbody fundamental watershed polygon at that location in the stream network.

Fundamental watershed polygons that are not waterbody fundamental watershed polygons and do not contain a flow edge (these are usually called "face unit" polygons) should receive a local order and magnitude of zero (0). This indicates that these fundamental watershed polygons do not contain any flows and drain directly into a waterbody, stream, or the ocean.