Ministry of Agriculture and Lands
Base Mapping & Geomatic Services

Freshwater Atlas v1.3

SE Generation Technical Issues

Prepared for

Base Mapping & Geomatic Services
Integrated Land Management Bureau
Ministry of Agriculture and Lands

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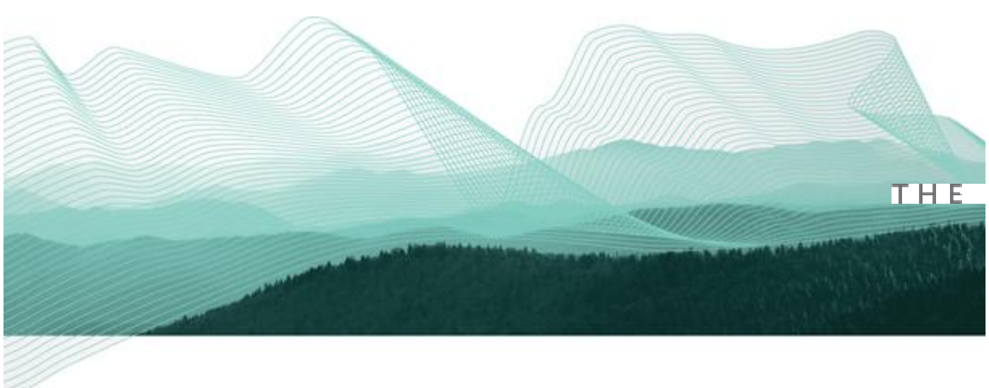
Version: 0.8 (DRAFT)
Last Updated: April 26, 2007
FWA-SE.TechnicalIssues.v0.8.doc



THE GEOSPATIAL EXPERTS

REVISION HISTORY

Date	Version	Author	Changes
Mar. 28, 2007	0.4	Refractions Research Inc. *Martin Davis* *Kevin Neufeld* *Emily Gouge*	Initial version – containing outstanding issues for smoothing data.
Apr. 12, 2007	0.5	Refractions Research Inc. *Kevin Neufeld* *Emily Gouge*	Updated uphill edge counts (tables 1&5) and added new elevation pictures of unregulated lakes Updated uphill segments section with further examples and comments about flipping edges. Added wetland skeleton outstanding issue.
Apr. 17, 2007	0.6	Refractions Research Inc. *Kevin Neufeld*	Replaced text occurrences of “5D” with “SEG”
Apr. 26, 2007	0.7	Refractions Research Inc. *Kevin Neufeld* *Emily Gouge*	Added “Elevation Inconsistency” figure. Added decision for excluding wetland skeletons. Added current decisions for node spike detection and removal, vertex spike detection and removal, lake levelling, and dealing with uphill segments. Added comments about gradient computation.
Apr. 4, 2008	0.8	Refractions Research Inc. Ben Brehmer	Altered document wherever necessary to reflect FWA 1.3 deliverable.

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COMPUTATION OF REFINED ELEVATIONSTREAM NETWORK DEFINITION

THE STREAM NETWORK FOR COMPUTING REFINED ELEVATION WILL INCLUDE:

all single line observed streams in BC or extra-jurisdictional data that connects BC streams (1000, 1050, 1100, 1150, 2000, 2300)

all lake, river, and wetland skeletons in BC or extra- jurisdictional data that connects BC streams (1200, 1250, 1300, 1350, 1400, 1410, 1425,1450, 1475) in BC

The following sections discuss some cases which require special rules.

Inferred Edges

The FWA data includes 1410 and 1425 edges, which are inferred (non-observed) connector edges added manually to ensure connectivity. 1410's will be snapped to adjacent nodes and be assigned a raw elevation. Note that these edges will not be guaranteed to be monotonically decreasing,.

Including inferred edges will force accommodating the inconsistent uphill elevations in the adjusted values elsewhere in the network, which could lead to large changes in elevation from the raw values.

The implications of **excluding** inferred edges are:

- the connected stream network (i.e. including inferred edges) will not be monotonically decreasing.
- the observed stream network (i.e. without inferred edges) will be monotonically decreasing.

From BMGS Technical Meeting (February 18, 2008):

> Assign raw elevation to 1410's and snap endpoints to adjacent nodes. After the test LRDW 3D load process it was discovered that **all** edges in the stream network need to have an elevation value assigned to them due to database constraints for a 3D SDE layer. It was decided that the option of assigning 1410's an obviously invalid elevation (ie. -999) would lead to confusion.

From Dave Tesch (March 30, 2007):

> I was able to talk with Dan and George about calculating Z' on the 1410 connectors and they both agree with the suggestion from Refractions that it shouldn't be done.

Unfortunately, both Tony Cheong and Art Tautz have been away so I was not able to get any comments on how this situation has been handled by other business areas.

Regards,
D.

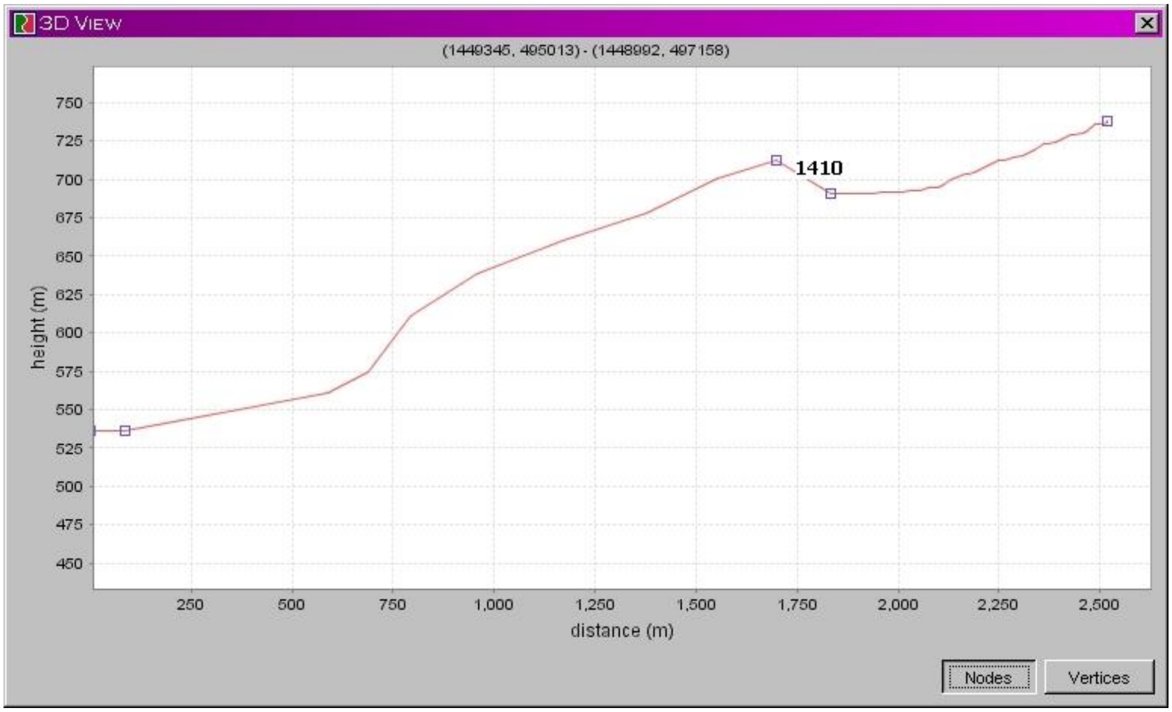


Figure 1: Uphill Inferred Edge

The following table shows the magnitude of uphill inferred edges.

Table 1: Uphill Stream Segments

Height Difference (m)	Observed	Inferred (1410's, 1425s)	River Skeletons
0 - 1	2164	2131	96580
1 - 2	41118	2163	26008
2 - 3	12248	1488	6865
3 - 4	4251	1113	2409
4 - 5	1574	944	1050
5 - 6	455	869	421
6 - 7	36	737	199
7 - 8	43	646	135
8 - 9	24	592	57
9 - 10	12	514	35
10 - 20	58	3360	84
20 - 30	34	1251	15
30 - 40	18	544	4
40 - 50	13	319	3
50 - 60	6	168	2
60 - 70	7	97	1
70 - 80	1	55	
80 - 90	1	44	1
90 - 100	2	22	
100 - 200	19	42	2
200 - 300	5	6	
300 - 400	1		2
400 - 600	2	2	
600 - 800			
800 - 900	2		
900 - 1000	1	1	

Reviewing the larger differences indicates:

the 900 – 1000m difference was a result of a data spike in the TIN. This particular data spike was a result of an AreaOfExclusion:TRIM having an elevation value of 0. It has subsequently been decided that all AreaOfExclusion:TRIM features with an elevation value of 0 will be excluded from the rawZ TIN.

e end

Many of the differences are a result of 1410’s drawn through glaciers as shown below.

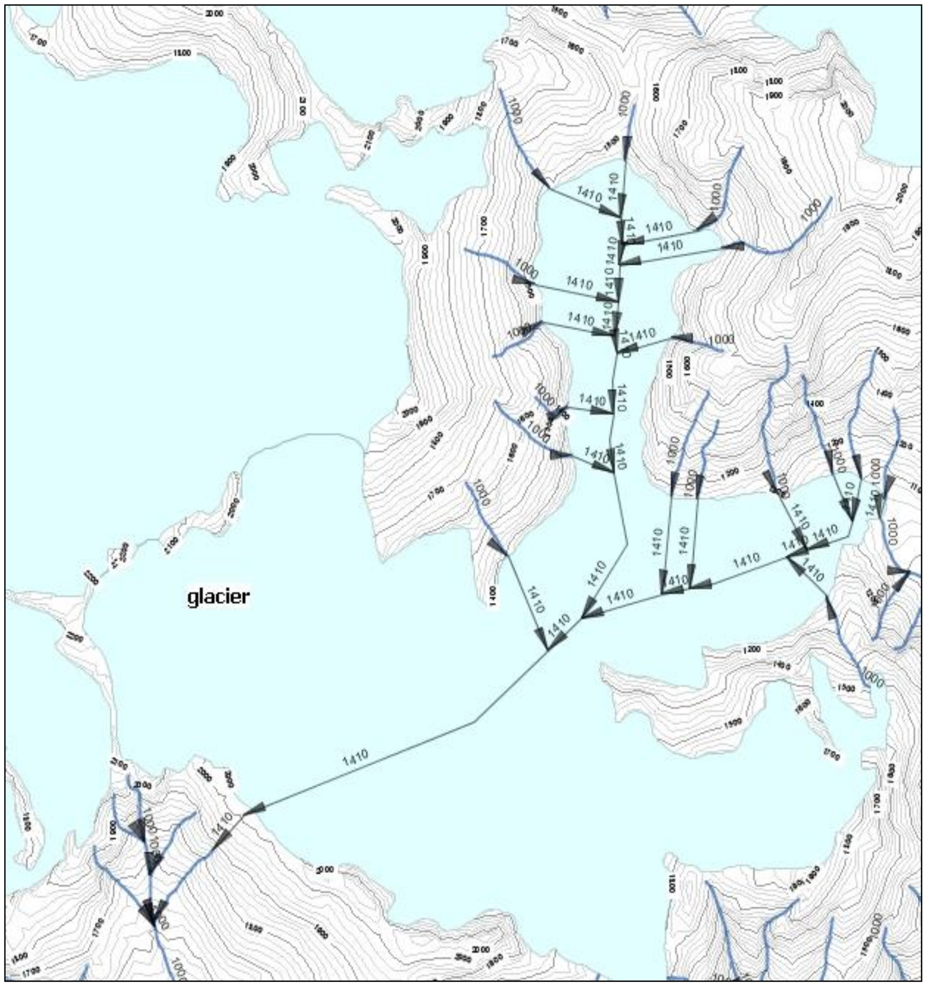


Figure 2: Uphill Glacer 1410s

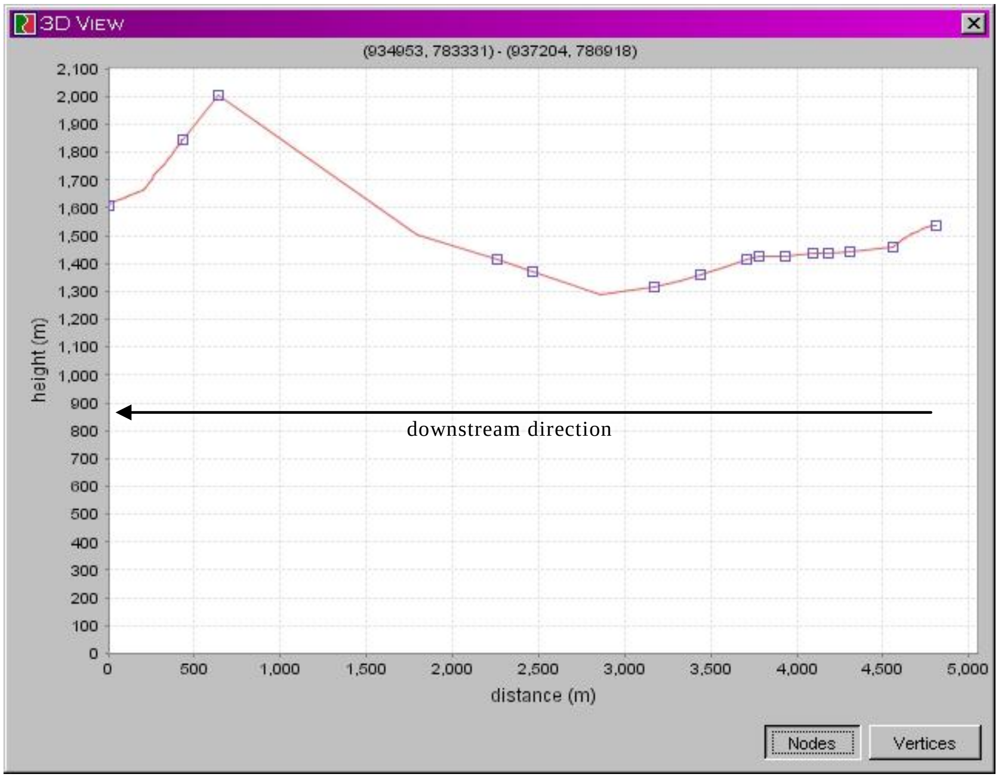


Figure 3: Glacier Uphill 1410 Profile

The remaining differences appear to be cases where 1410s are drawn over hills/mountains (see example below)

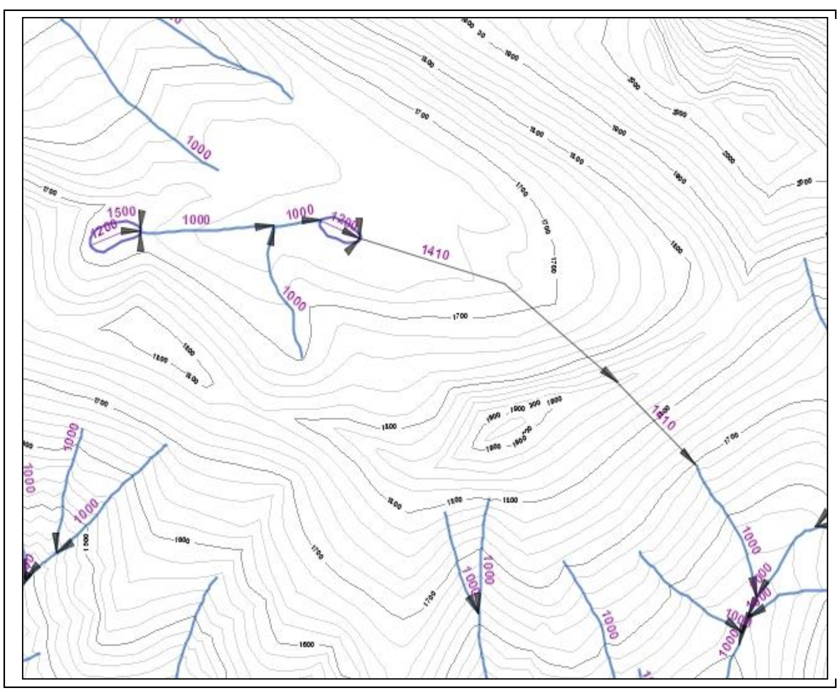


Figure 4: Uphill Inferred Edges with Contours

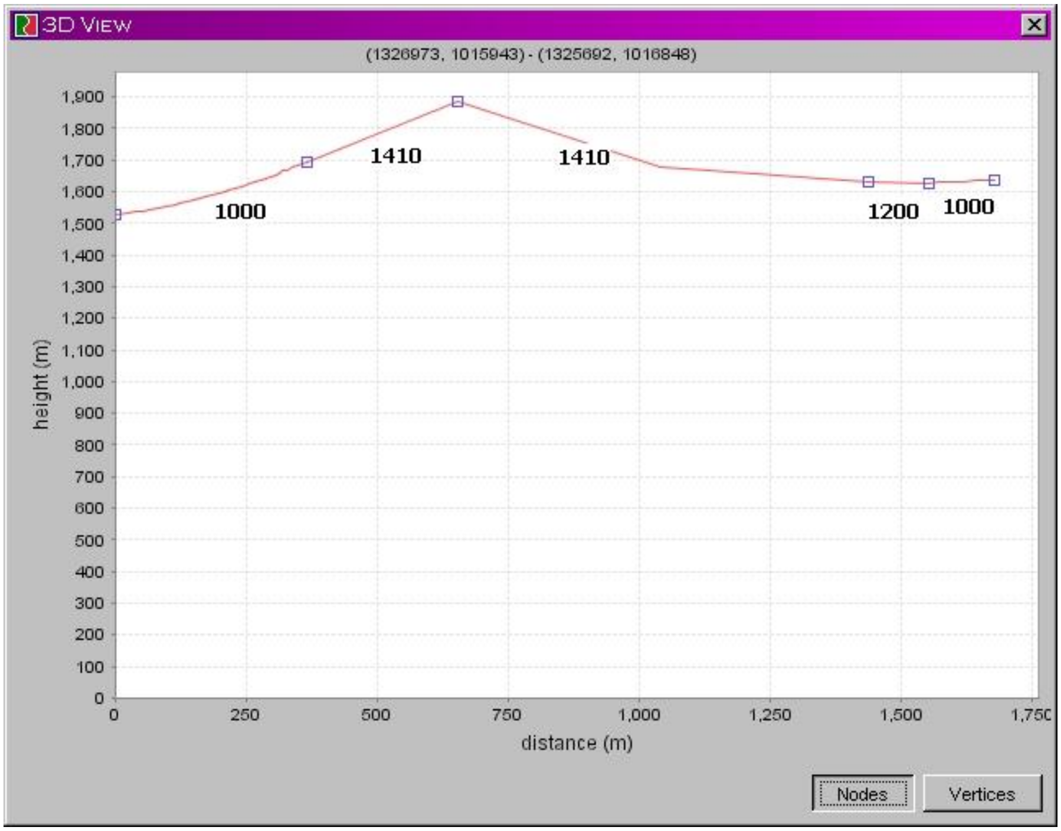


Figure 5: Uphill Inferred Edge Profile

Extra-Jurisdictional Edges

Some streams in BC flow in and out of the province. The FWA dataset has connected these with observed streams from the extra-jurisdictional data where available, and inferred connectors (1410s/1425s) where reasonable assumptions could be made about stream flow.

Recommendation:

Use the same rule as in-province edges. Observed extra-jurisdictional edges will be included in the stream network; inferred extra-jurisdictional edges will be excluded.

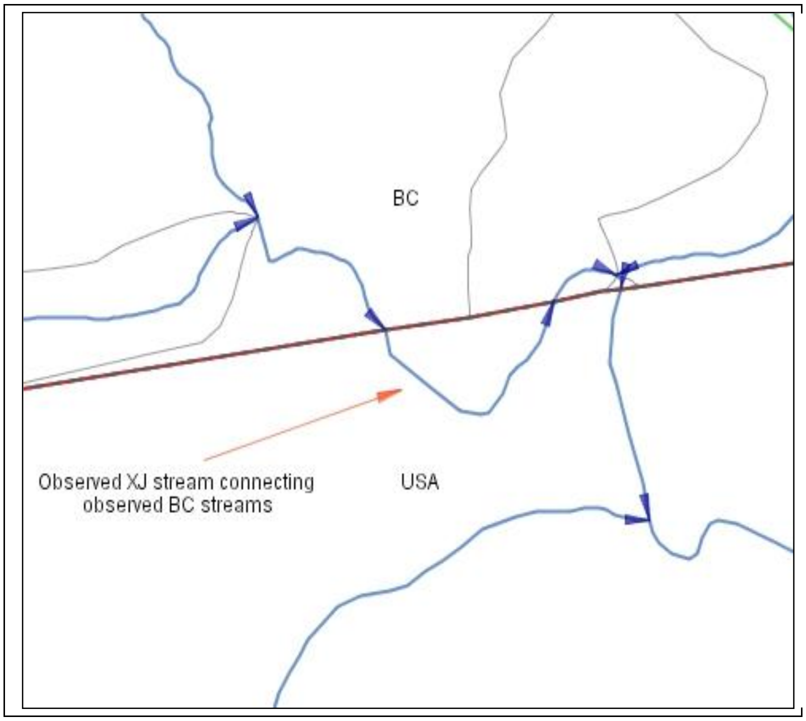


Figure 6: Extra-Jurisdictional Inferred Stream Edges

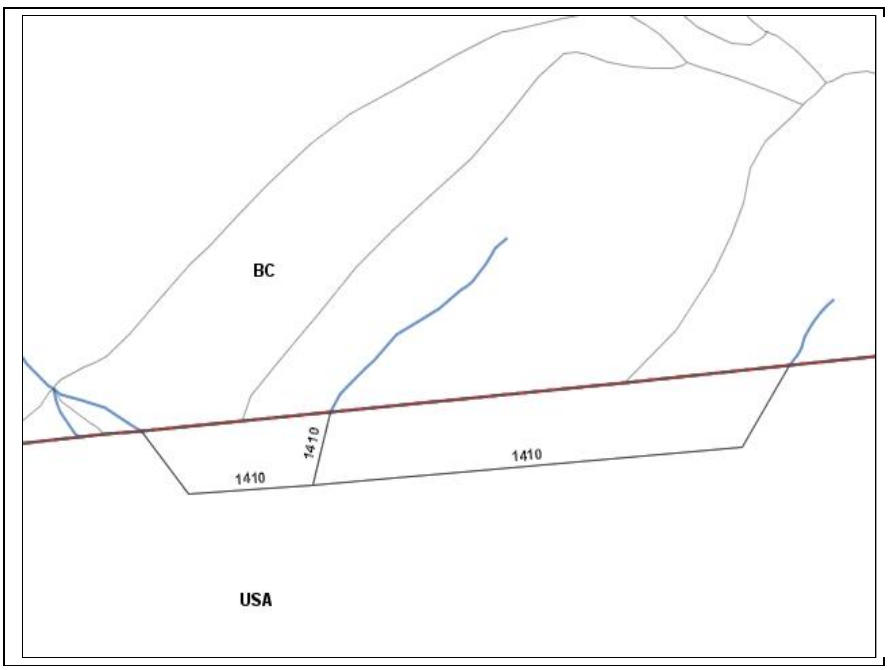


Figure 7: Extra-Jurisdictional Observed Stream Edges

Wetland Skeleton Edges

Skeleton lines (1200, 1300, 1400) which occur in wetlands are similar in nature to 1410s and 1425s. Many of these will flow uphill which, if included in the stream network, can have similar affects as including 1410's and 1425's.

We recommend these be excluded from the stream network.

As per the meeting on April 24, 2007 the wetland skeletons will be excluded from the stream network.

NODE SPIKES

Examples

In the raw data there are cases where stream confluences with other streams, lake banks, river banks, or wetlands "spike" out of the range of data round the node. These node spikes may skew the results of the smoothing process if not identified and preprocessed.

The following pictures show an example of a node spike. The node spike (elevation 155m) occurs at the confluence in the stream network that flows through a wetland. The implications of this particular node spike are that the TIN built for draping raw elevations values has a large sink in the surface and all raw elevation draped watershed boundary lines are skewed.

The bold vertex labels are the raw elevations values in meters associated with the vertex. The italic labels along the edge are the edge codes (1050 = observed stream; 1700 wetland banks; 5100 watershed boundary lines).

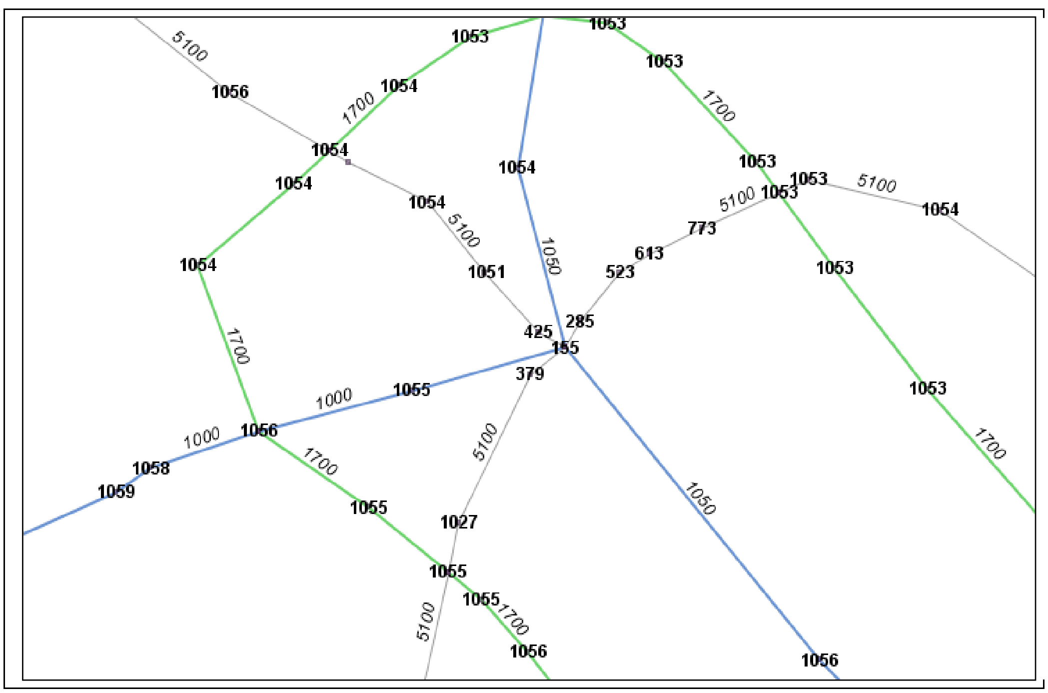


Figure 8: Node Spike in Stream Network

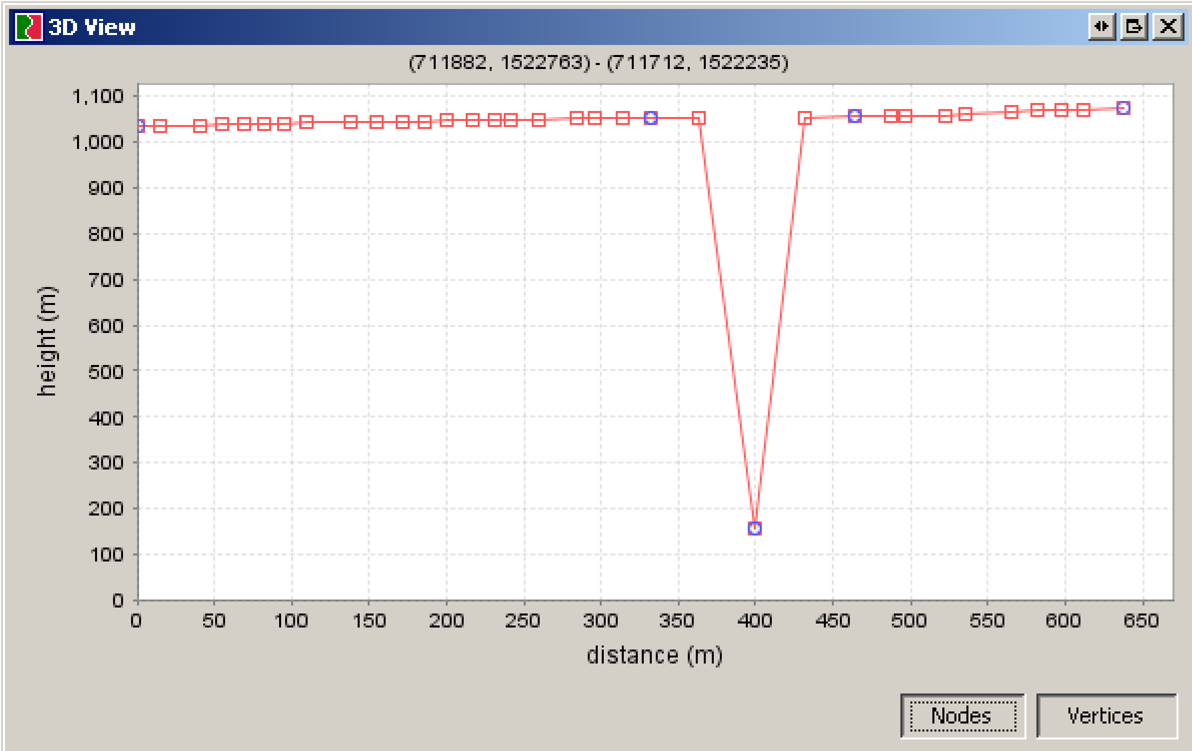


Figure 9: Node Spike Profile

Data Statistics

The following histograms show probable vertex/node spikes in observed features. That is, the total height of consecutive uphill segments greater than 5 meters.

Table 2: Uphill Consecutive Segment Height

total consecutive uphill elevation change (meters)	lake banks	river banks	wetland banks	observed streams
0-5	230978	95763	1189832	723867
5 - 100	120	252	44179	1696
100 - 200	1	0	6	24
200 - 300	0	0	2	8
300 - 400	0	1	2	5
400 - 500	0	0	0	1
500 - 600	1	0	0	6
600 - 700	0	0	0	1
700 - 800	0	0	2	1
800 - 900	1	1	1	7
900 - 1000	2	0	15	4
1000 - 1100	1	0	0	1
1100 - 1200	0	0	0	2
1200 - 1300	0	0	0	2
1300 - 1500	0	0	0	3
1500 - 1600	0	0	1	2
1600 - 1700	0	0	0	1
1700 - 2100	0	0	0	1
2100 - 3000	0	0	0	1
3000 - 7200	0	0	0	1
7200 - 8800	0	0	1	2
8800+	0	0	0	1

Identifying Node Spikes

Node spikes are identified by analyzing the angle created by the elevation change between adjacent vertices. The current tolerance is 45 degrees.

LAKE NODE LEVELLING

Lakes are to be leveled to a "cleaned-average" of all observed lake bank vertices. A "cleaned-average" is used to eliminate the influence of erroneous data.

The cleaned-average has been defined as the average of the 90-95th percentile of elevation values at all vertices.

The following table contains the standard deviations of the raw elevations for all BC lakes.

Table 3: Lake Standard Deviation Histogram

Standard Deviations	Number of Lakes
0 – 1	384827
1 – 2	2782
2 – 3	204
3 – 4	17
4 – 5	4
5 – 6	3
6 – 7	1
7 – 8	2
8 – 9	1
9 – 10	0
10 – 20	1
20 – 100	1
100 – 200	1
200 – 400	2
400 +	1

The large standard deviation results (i.e. > 10) are a result of the following cases:

Half the vertices along the lake are at a given elevation, the other half of the vertices are set to 0, -1, or some other erroneous value.

A large, multi-vertex spike occurs on the lake bank the affects enough vertices to significantly affect the average.

Removing the outliers and stripping erroneous {0, -1} values from the average should handle all lakes satisfactorily.

Examples of Lake Elevations

The following table contains elevation information for a few of the larger lakes in BC. Leveling these lakes has the following implications:

5-10m drops will be created at some inputs/outputs of the lake

there is potential for upstream streams to be raised between 5-10m

To mitigate the introduced drops it may be possible to level out the drop over all the vertices of the containing edge, while attempting to preserve the original profile of the stream as much as possible. This may or may not be effective.

Table 4: Large Lake Statistics

Lake Name	Lake Area	Min Height	Max Height	Diff	Average Height	Standard Deviation
Great Central Lake	53km^2	85	93	8	86	0.90
Kennedy Lake	65km^2	3	13	10	8	2.1
Kootenay Lake	422km^2	528	543	15	534	4.10
Nechako Reservoir	895 km^2	849	860	11	855	1.50
Shuswap Lake	307km^2	344	360	16	348	1.9
Williston Lake	1727 km^2	667	684	17	674	3.06

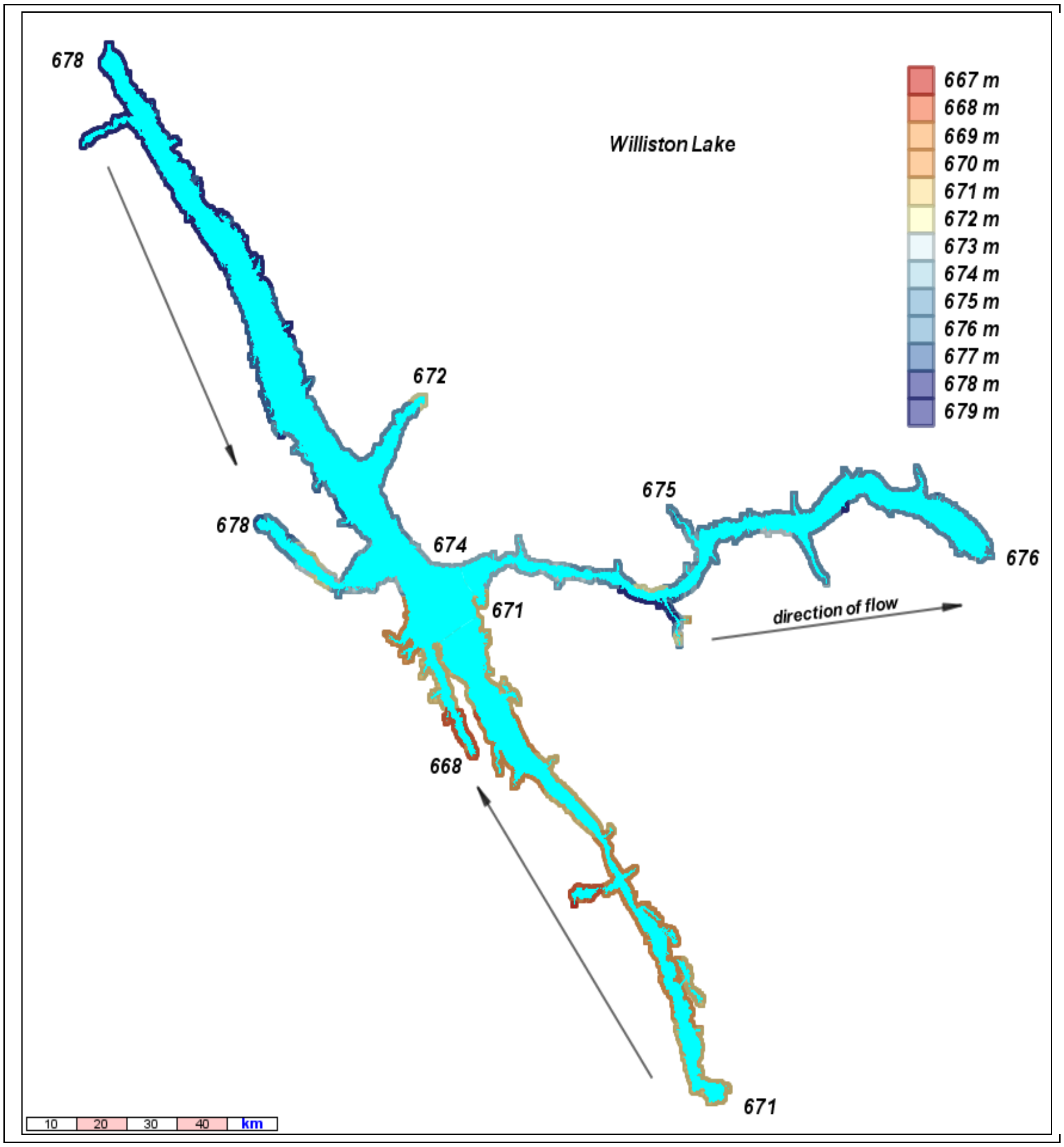


Figure 10: Williston Lake Elevations: 95% - 678m

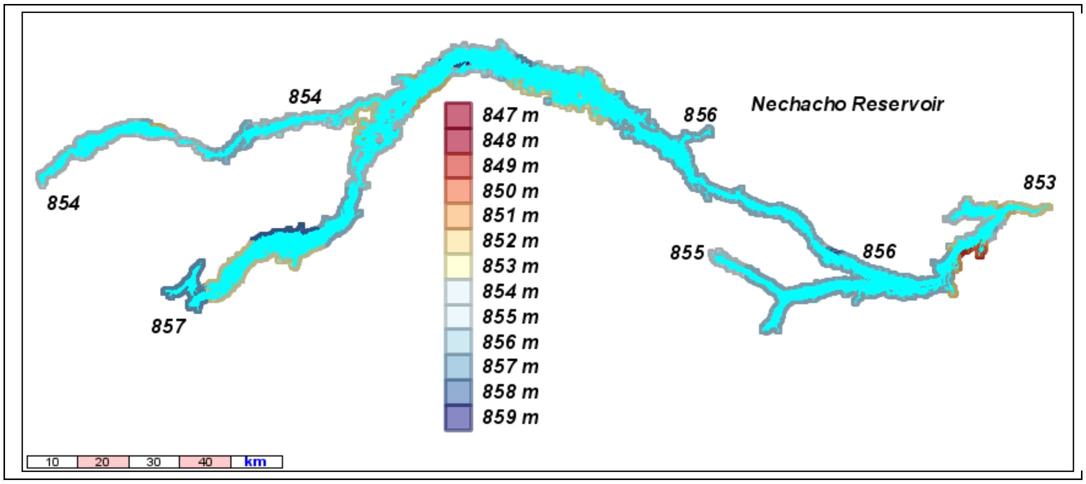


Figure 11: Nechacho Reservoir: 95% - 856m

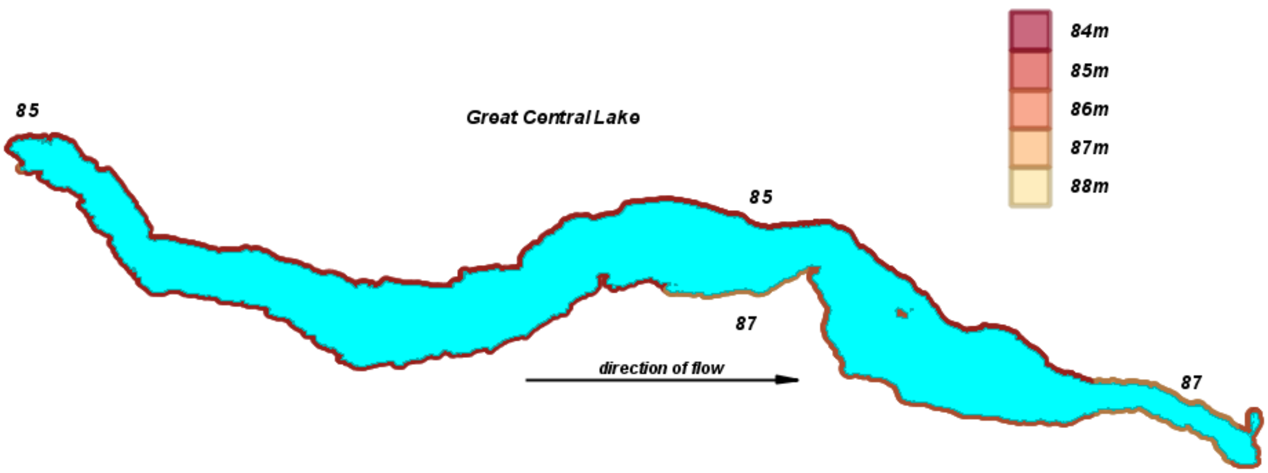


Figure 12: Great Central Lake: 95% - 87m

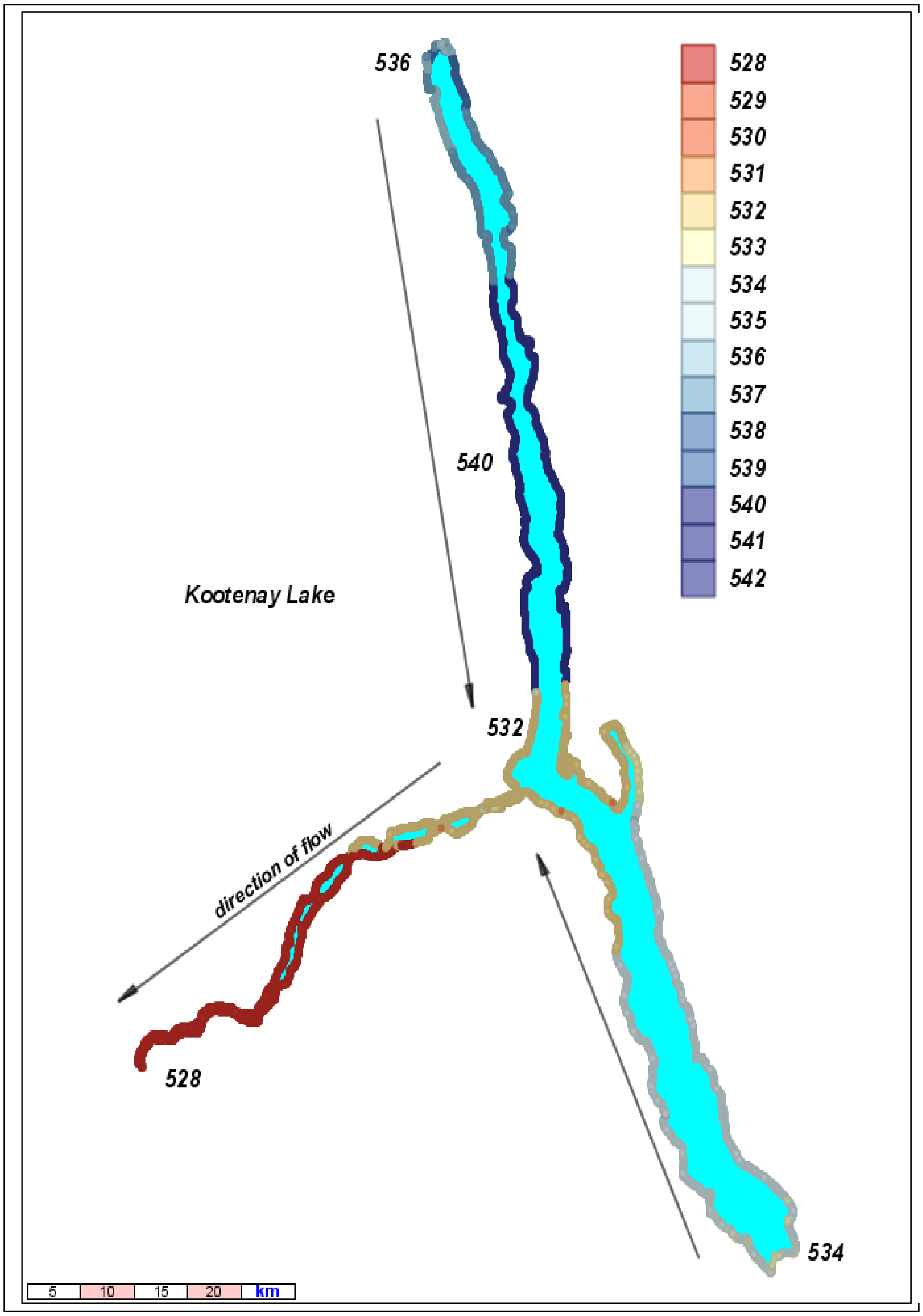


Figure 13: Kootenay Lake: 95% - 540m

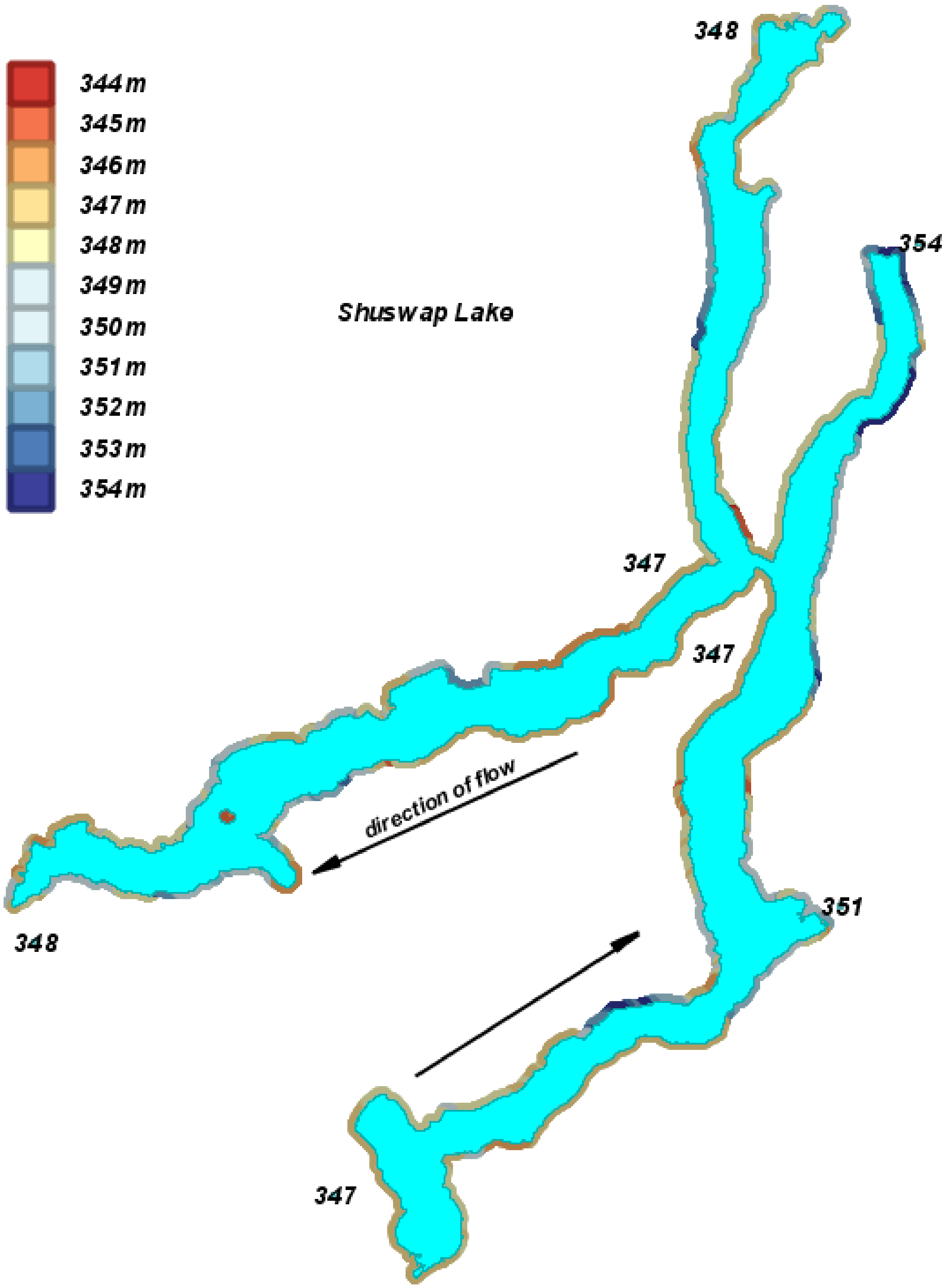


Figure 14: Shuswap Lake: 95% - 352m

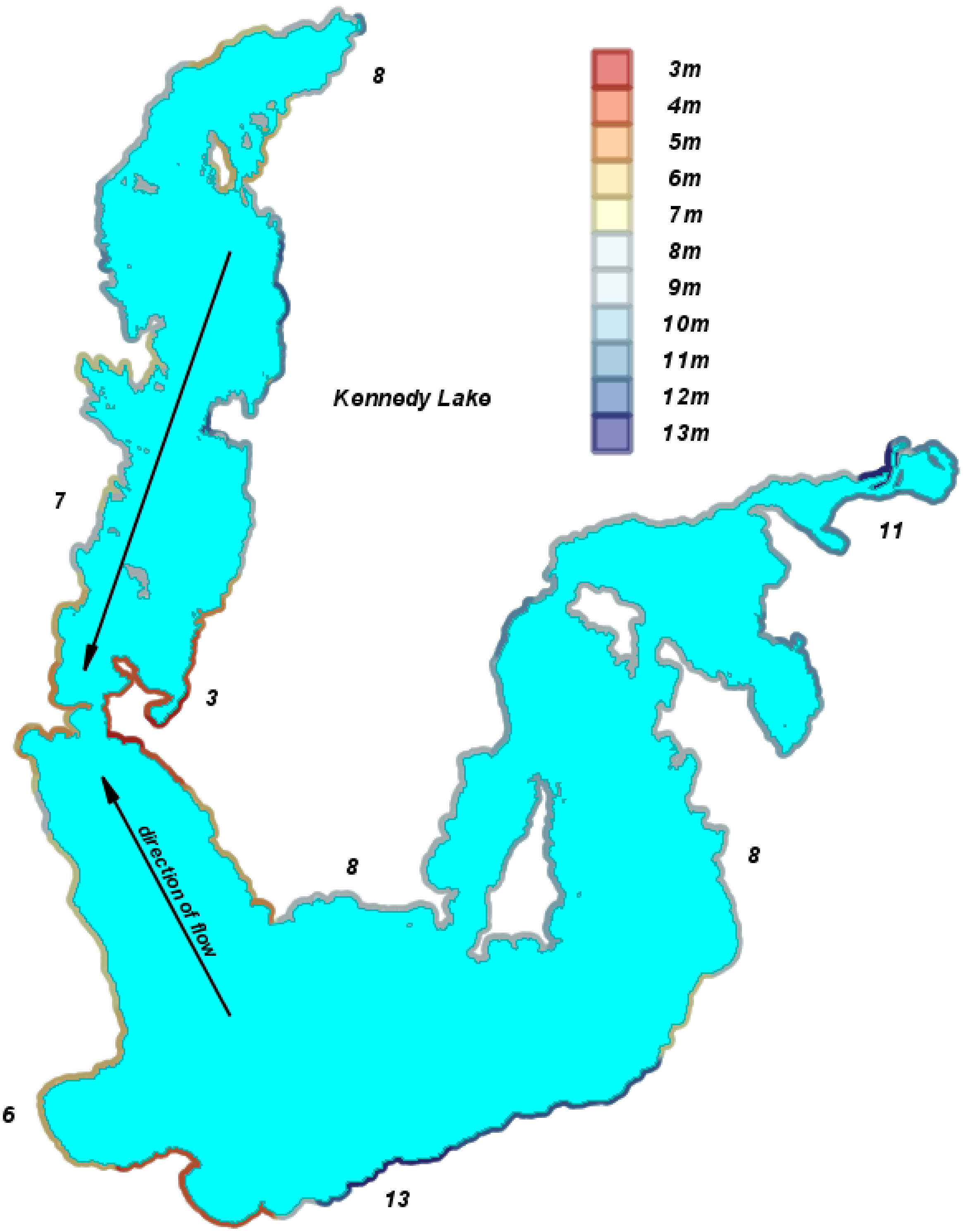


Figure 15: Kennedy Lake: 95% - 11m

NODE MONOTONICITY

Obviously Inconsistent Lake Elevation Data

The following image shows an example of a non-monotonic node network occurring at north end of Revelstoke Lake. We believe this situation is due to different mapping dates and/or data that shows the effects of reservoir draw-down.

Recommendation:

Raise the obviously incorrect elevations to the deemed lake level via explicit manual intervention.

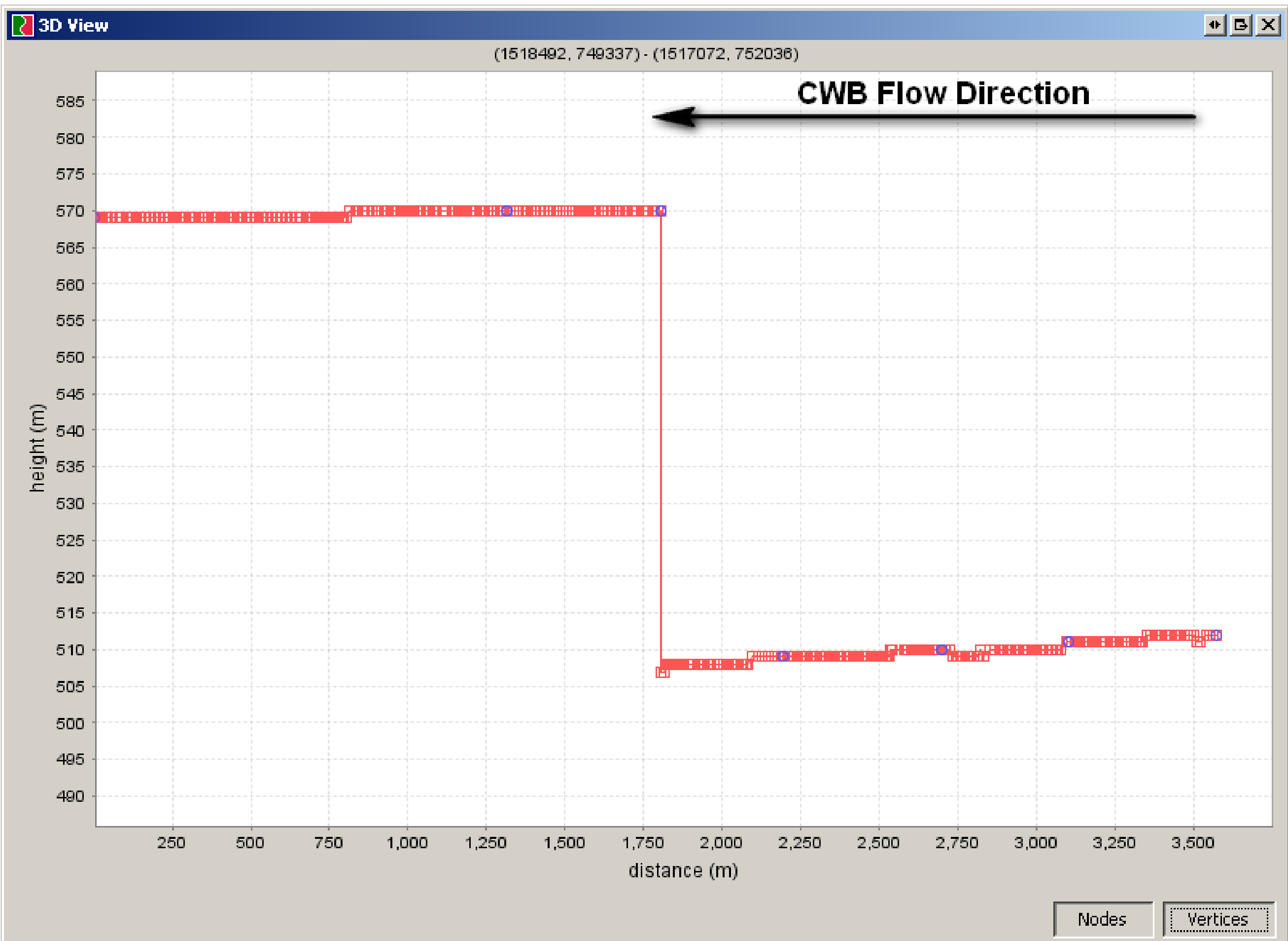
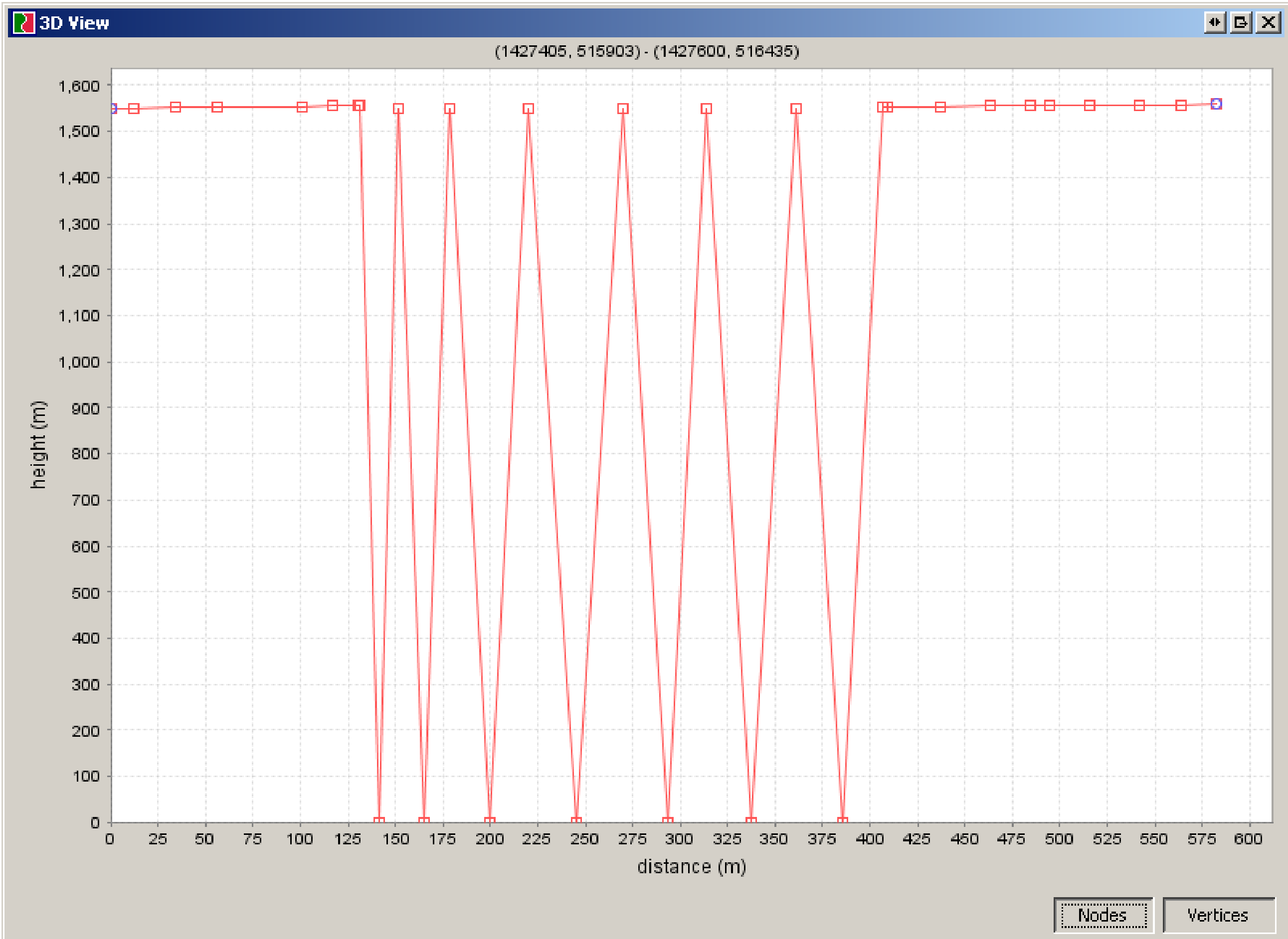


Figure 16: Double-line river flowing into a lake

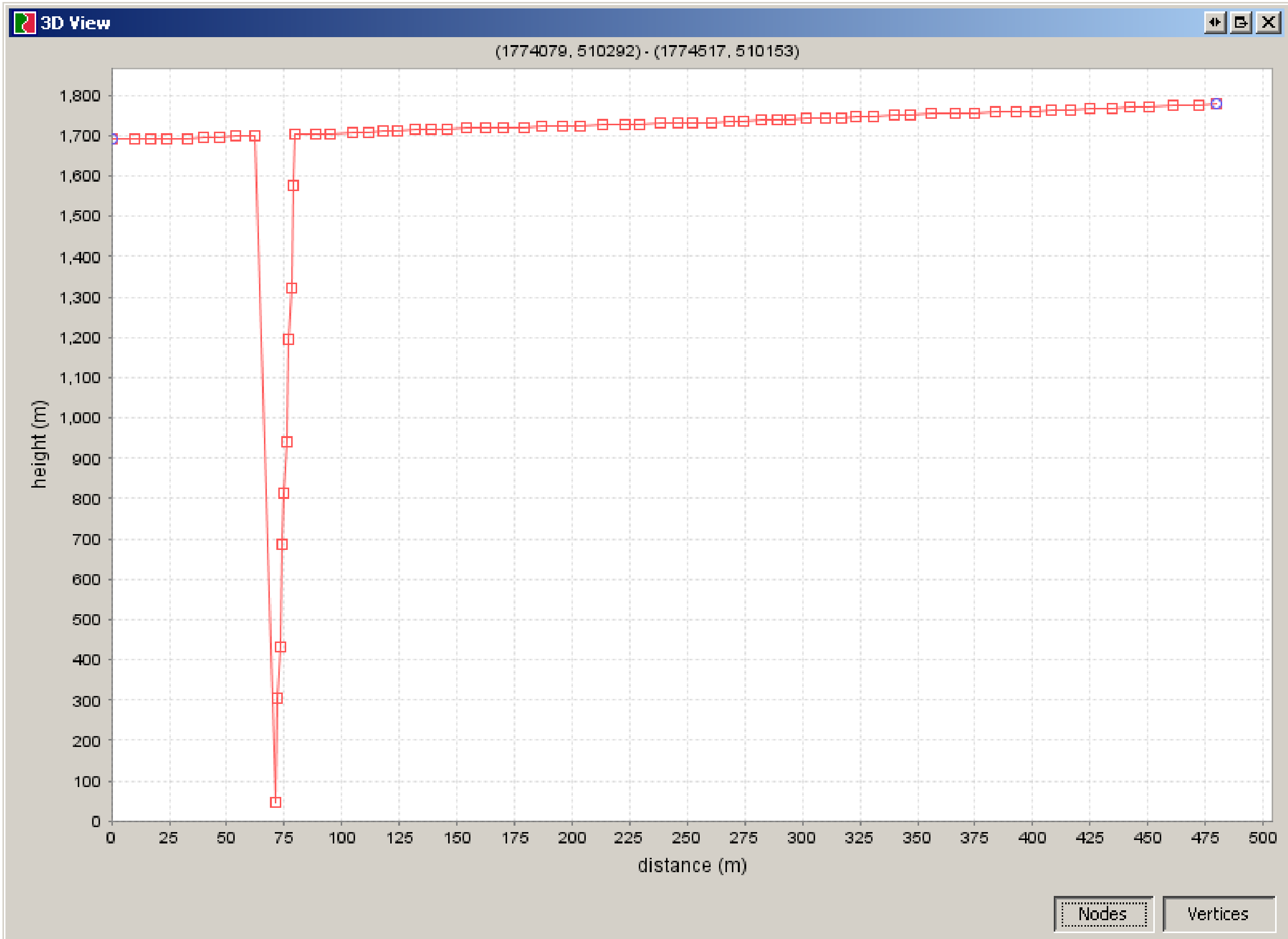
STREAM EDGE VERTEX SPIKE REMOVAL

Examples



CODE: 1000 - observed stream

Figure 17: Single Vertex Spikes



CODE: 1000 - observed stream

Figure 18: Multi Vertex Spike

Algorithm

Vertex spikes are treated the same as node spikes for identifing and fixing.

The existing Barrodale code has the following algorithm:

```
for each vertex spike
     Intersect lines through a node of interest.
     Remove any spikes on the merged lines.
     Take the z value at the node.
```

STREAM EDGE SMOOTHING

After the node network has been monotonized, individual stream edges can be monotonized and smoothed relative to the values on their end-nodes.

The goal of the smoothing process is to remove the 1m "stair-stepping" artifacts resulting from the TRIM 1m elevation precision model. The smoothing should be limited so that it preserves the character of the stream elevation as far as possible.

Example

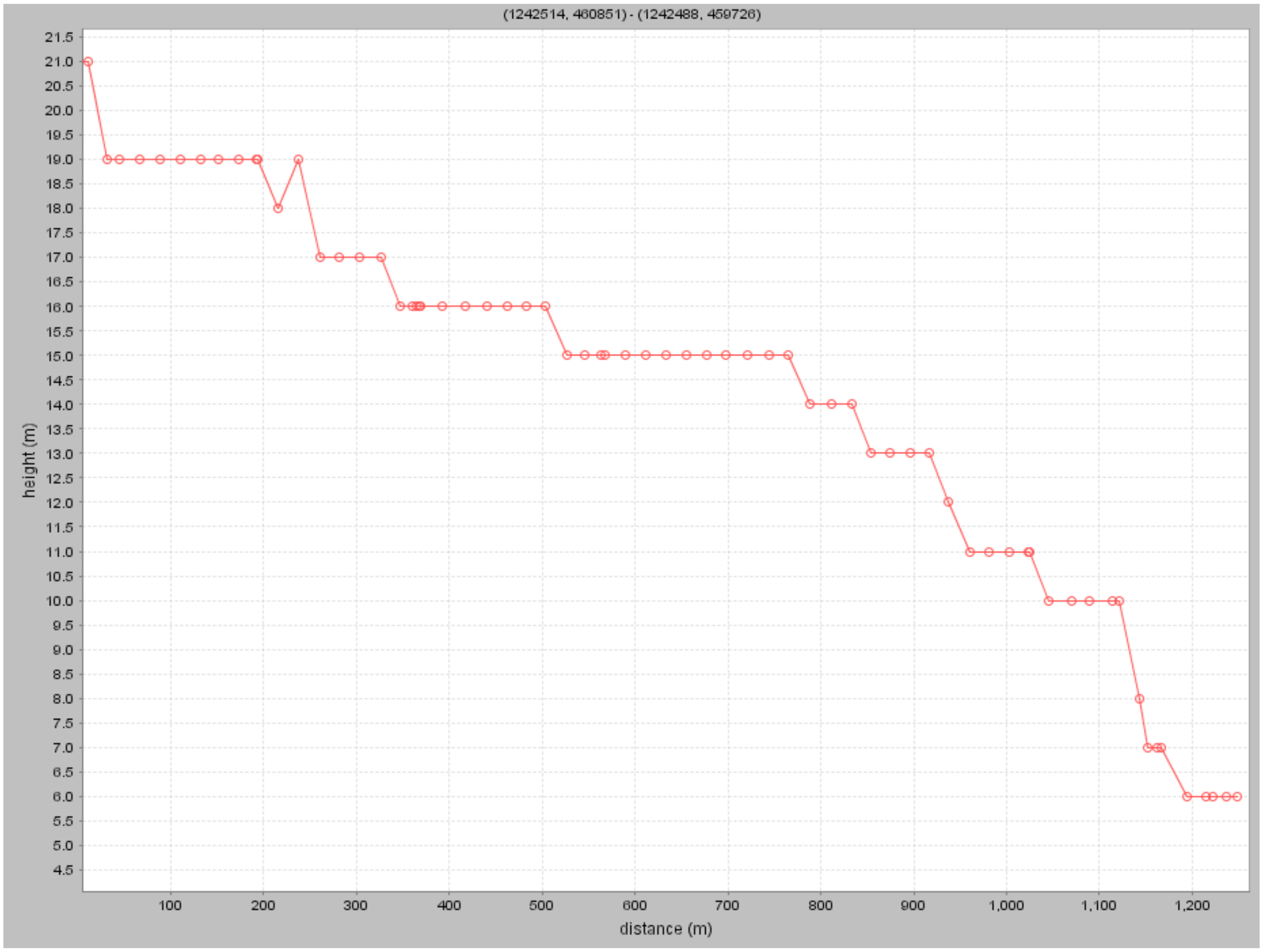


Figure 19: Example of Stair-Stepping

Algorithm

The following options exist for smoothing stream edges:

1. Use a modified Barrodale line fitting algorithm.
   The Barrodale line fitting algorithm produces a least squares fitting line through the elevation values of the stream edge. However, the algorithm does not guarantee monotonicity. It may be possible to modify the algorithm to preserve monotonicity. It has been determined that this algorithm is not computationally expensive.
2. **[Current Implementation]** Use the Barrodale line fitting algorithm then rerun the vertex monotonicity step.
   This would involve running the existing Barrodale line fitting algorithm, then rerunning the software that creates monotonically decreasing vertex network. As with the previous option. It has been determined that the Barrodale line fitting algorithm is not computationally expensive.
3. Use a modified Douglas-Peuker algorithm.
   This would algorithm would based on the of a Douglas-Peuker algorithm, which modification to preserve the montonicity of the stream edges. This should result in a linear interpolation of vertices which contain small stair steps, but will preserve drops greater than a given tolerance factor.

ENTIRE STREAMS FLOWING UPHILL

There are cases where streams have likely been directionalized in the incorrect direction and thus according to the elevation data appear to flow up-hill. In some cases, this is due to the FWA data model forcing orientation upon arcs that is contrary to observed data.

Streams where the upstream node is >= 10m below the downstream node will be reviewed and errors fixed. The implications of not fixing the nodes <= 10 m will be reviewed and documented. If deemed necessary these may be review and fixed.

Example

The example shows the TRIM representation of a stream flowing through a large gravel fan into Tuchodi Lakes. One of the stream edges emerging from the gravel fan was mis-directionalized, which has caused a significant number of other network edges to become mis-directionalized as well. All of these edges flow uphill.

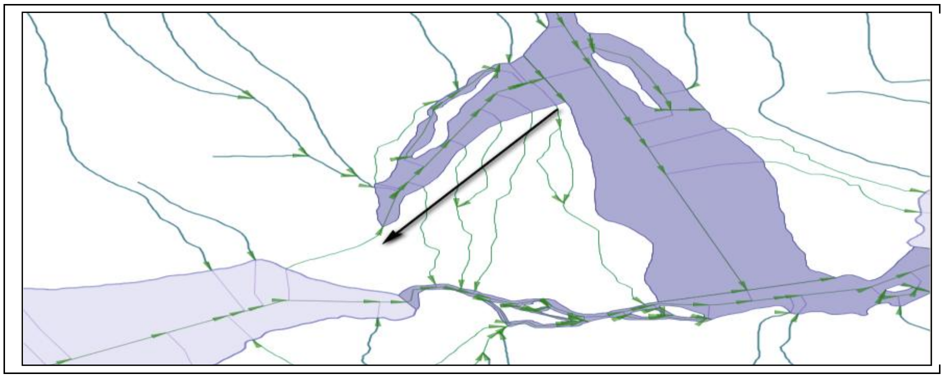


Figure 20: Tuchodi Lakes - Misdirectionalized Side Channel (Arrow shows downhill direction)

Figure 21: Tuchodi Lakes - Aerial View (note obvious real-world flow direction)

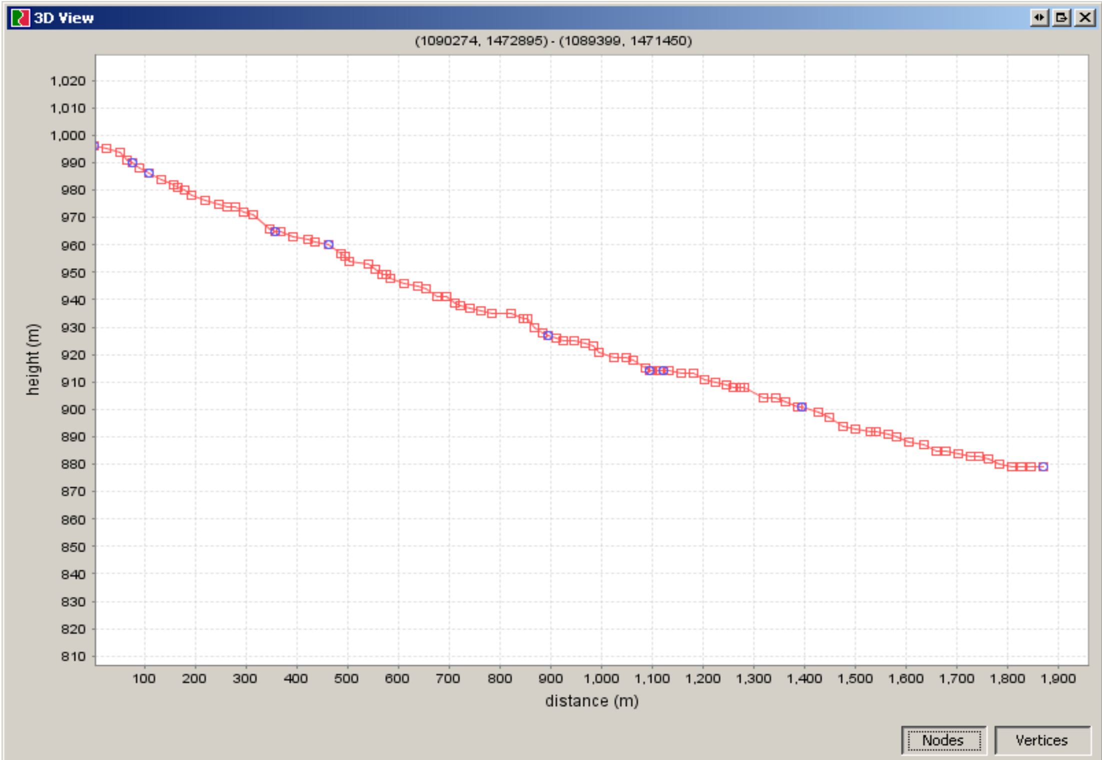


Figure 22: Tuchodi Lakes - Side Channel Profile

The following picture shows a schematic view of the example above. It shows the implications of performing no pre-processing on uphill segments and simply allowing the pure node-monotonizing algorithm to average out the elevation error.

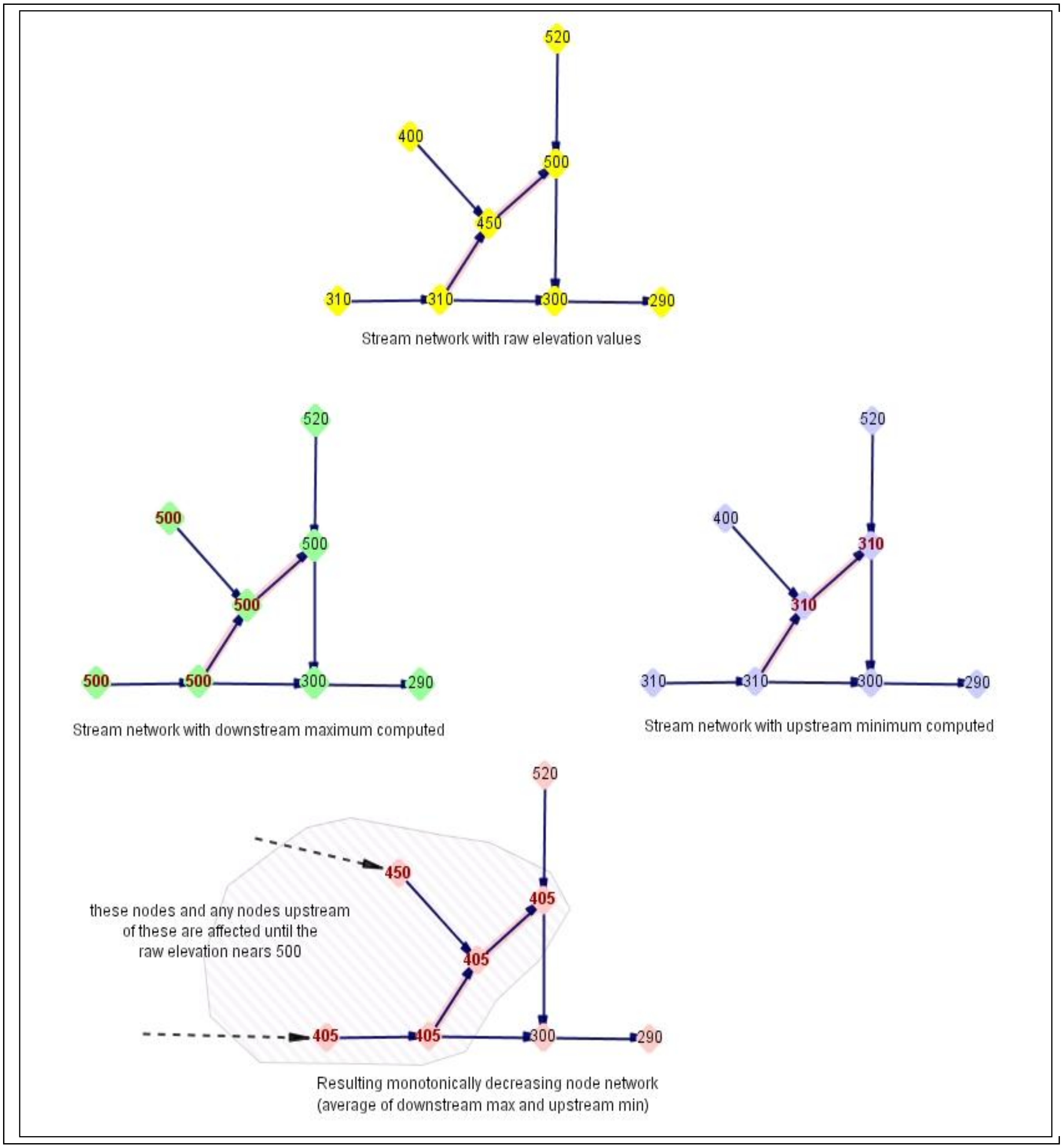


Figure 23: Tuchodi Lakes - Effect of not fixing uphill segments

Figure 24: Effect of Node-Monotonizing - Raising of Tuchodi Lakes by 60 meters

Data Statistics

The following table contains the counts of uphill edges (where the upstream node is lower than the downstream node)

Table 5: Uphill Stream Segments

Height Difference (m)	Observed	Inferred (1410's, 1425s)	River Skeletons
0 - 1	2164	2131	96580
1 - 2	41118	2163	26008
2 - 3	12248	1488	6865
3 - 4	4251	1113	2409
4 - 5	1574	944	1050
5 - 6	455	869	421
6 - 7	36	737	199
7 - 8	43	646	135
8 - 9	24	592	57
9 - 10	12	514	35
10 - 20	58	3360	84
20 - 30	34	1251	15
30 - 40	18	544	4
40 - 50	13	319	3
50 - 60	6	168	2
60 - 70	7	97	1
70 - 80	1	55	
80 - 90	1	44	1
90 - 100	2	22	
100 - 200	19	42	2
200 - 300	5	6	
300 - 400	1		2
400 - 600	2	2	
600 - 800			
800 - 900	2		
900 - 1000	1	1	

Resolving

All uphill segments are dealt with through manual intervention. Any uphill edges are preprocessed by re-orienting them.

Implications of Fixing Direction Errors

There are 175 observed stream edges and 29 river skeletons where the downstream node is greater than 10m above the upstream node. Some of these are a result of node spikes; but the majority are a result of streams that are mis-directionalized.

From reviewing approximately 30 of these cases there are very few (< 10%) which are '*simple'* (i.e. can be resolved by flipping a single edge and updating the primary/secondary coding).

Most fixes will involve removing 1410's, merging edges together, flipping streams, creating new 1410's, and updating routes. The reason that 1410s need to be altered is to meet the model requirement that all streams drain to the ocean. A flipped stream no longer drains along it's previous course, and so has to have a new draining edge (1410) added.

Examples

In all the examples below the arrows point downstream; the edges highlighted in pink are the edges flowing uphill.

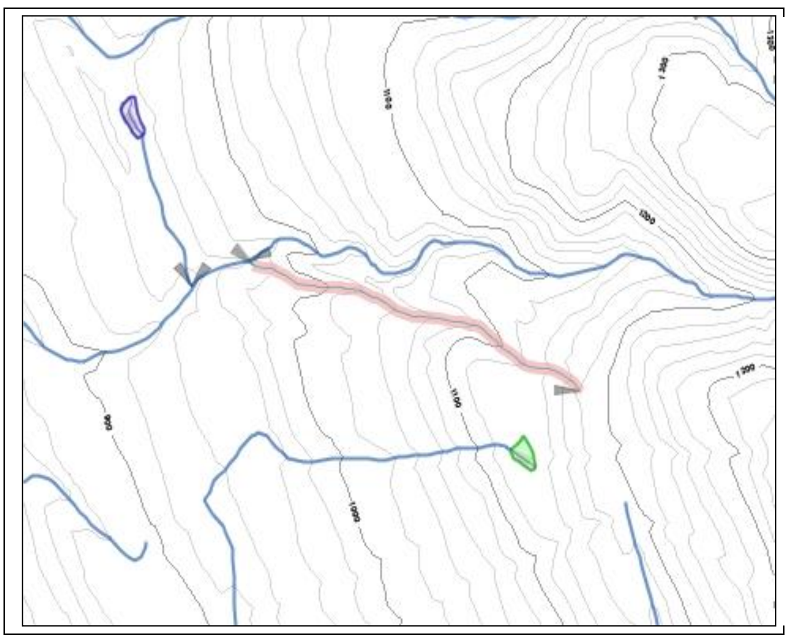


Figure 25: Mis-Directionalized Stream – Simple Case where only one edge needs to be flipped

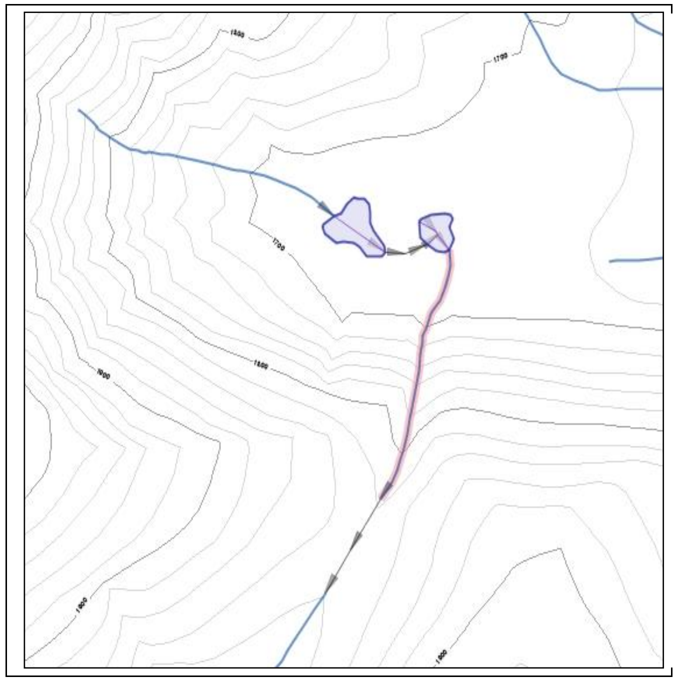


Figure 26: Mis-Directionalized Stream – incorrect 1410s would have to be moved to allow subnetwork to drain correctly

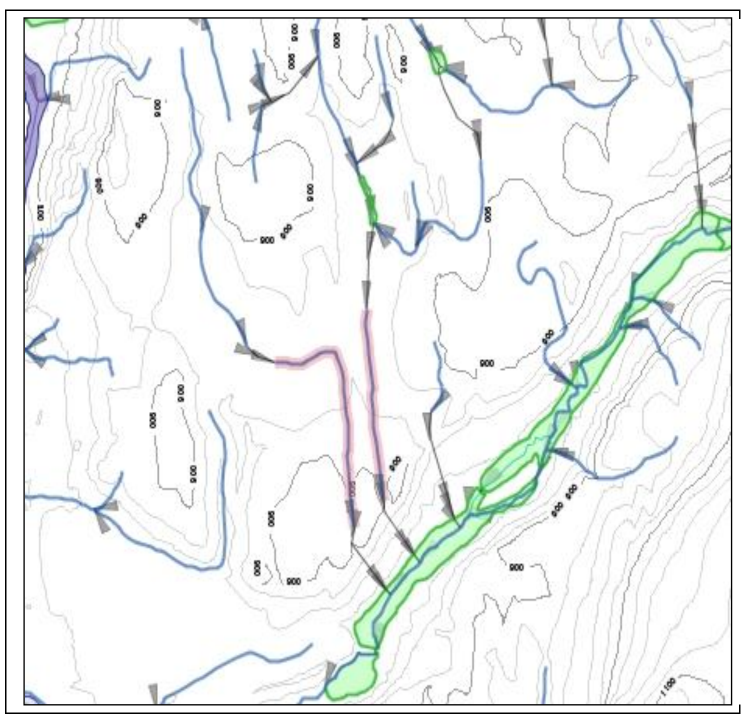


Figure 27: Mis-Directionalized Stream – two flipped edges, possibly complex decisions about 1410s

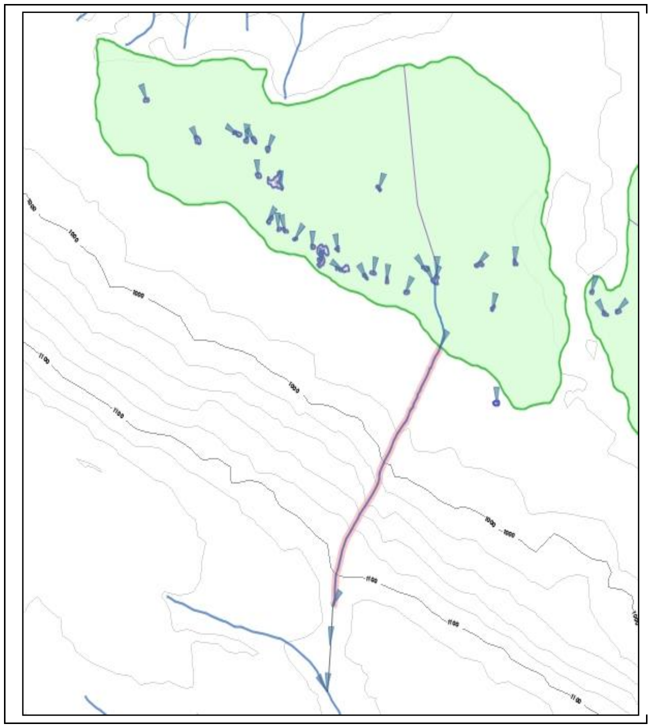


Figure 28: Mis-Directionalized Stream – needs to be flipped, 1410s redrawn

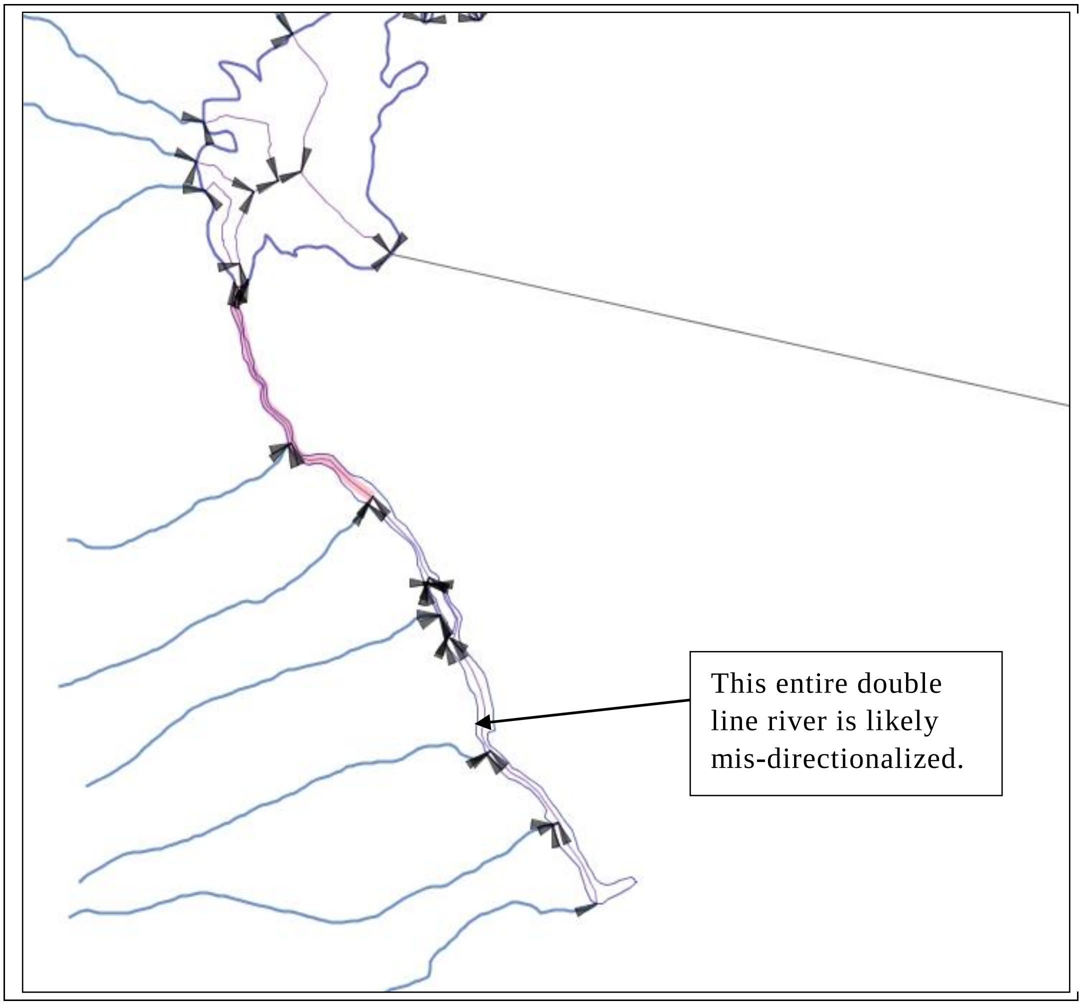
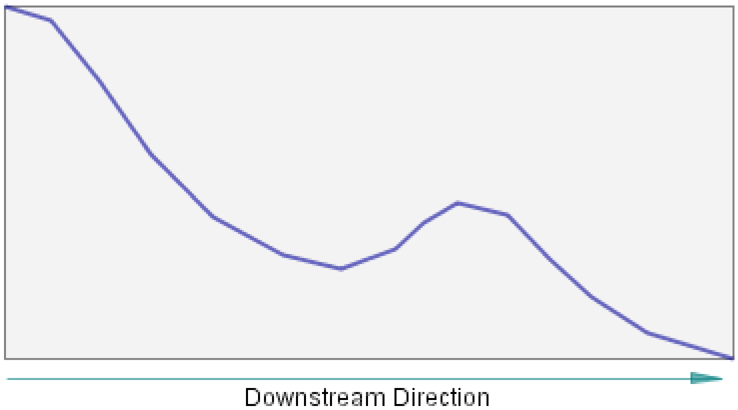


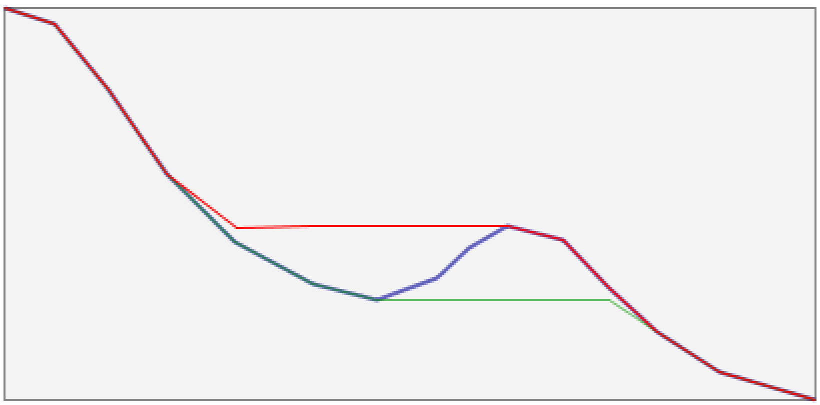
Figure 29: Mis-Directionalized Stream – lake should probably drain via double-line river, instead of the long straight 1410

Implications of NOT Fixing Direction Errors

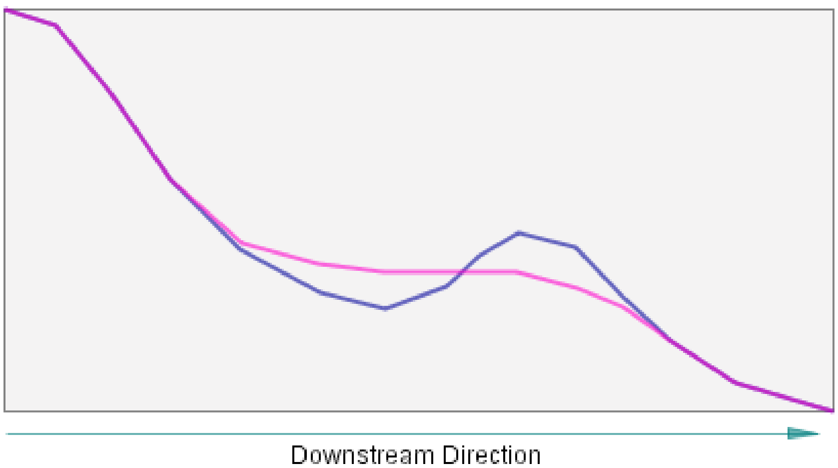
Consider the following stream profile:



In this case there is a part of the stream flowing uphill. When the monotonic network code is run it will compute the upstream minimum (green line) and downstream maximum (red line) for each point.



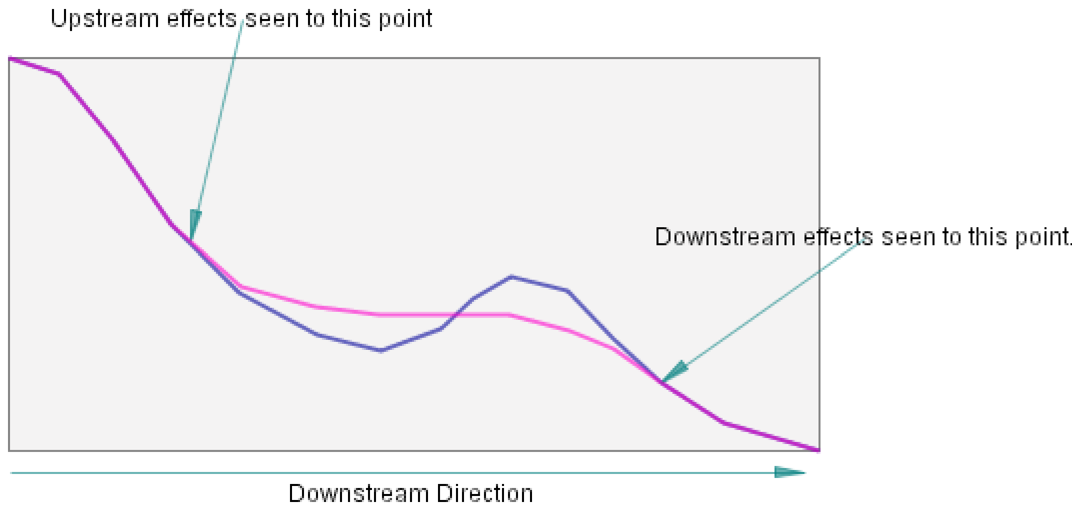
These two values are then averaged to compute the refined elevation (the pink line).



The result is that the raw z will be moved at most ½ the distance between the highest and lowest point on the uphill segments.

Streams which flow in to the area where the monotonic elevation was averaged may be flattened or contain waterfalls; however the maximum distance flattened or waterfall created will again be ½ the distance between the highest and the lowest points on the uphill segments.

The effects of the uphill segment will affect upstream streams until the upstream elevation is greater than highest point along the uphill segment and downstream streams until the downstream elevation is lower than the lowest point along the uphill segment.



LAKE BANK LEVELLING

This case is presented for interest only.

In this example, a small lake has a highly varying z-profile, with elevations over a 45 m range. This is likely due to the “lake” actually being a wetland (marsh). During leveling, this lake will have all elevations set to a single monotonized average value. This may result in drops or flooding being introduced on incident streams.

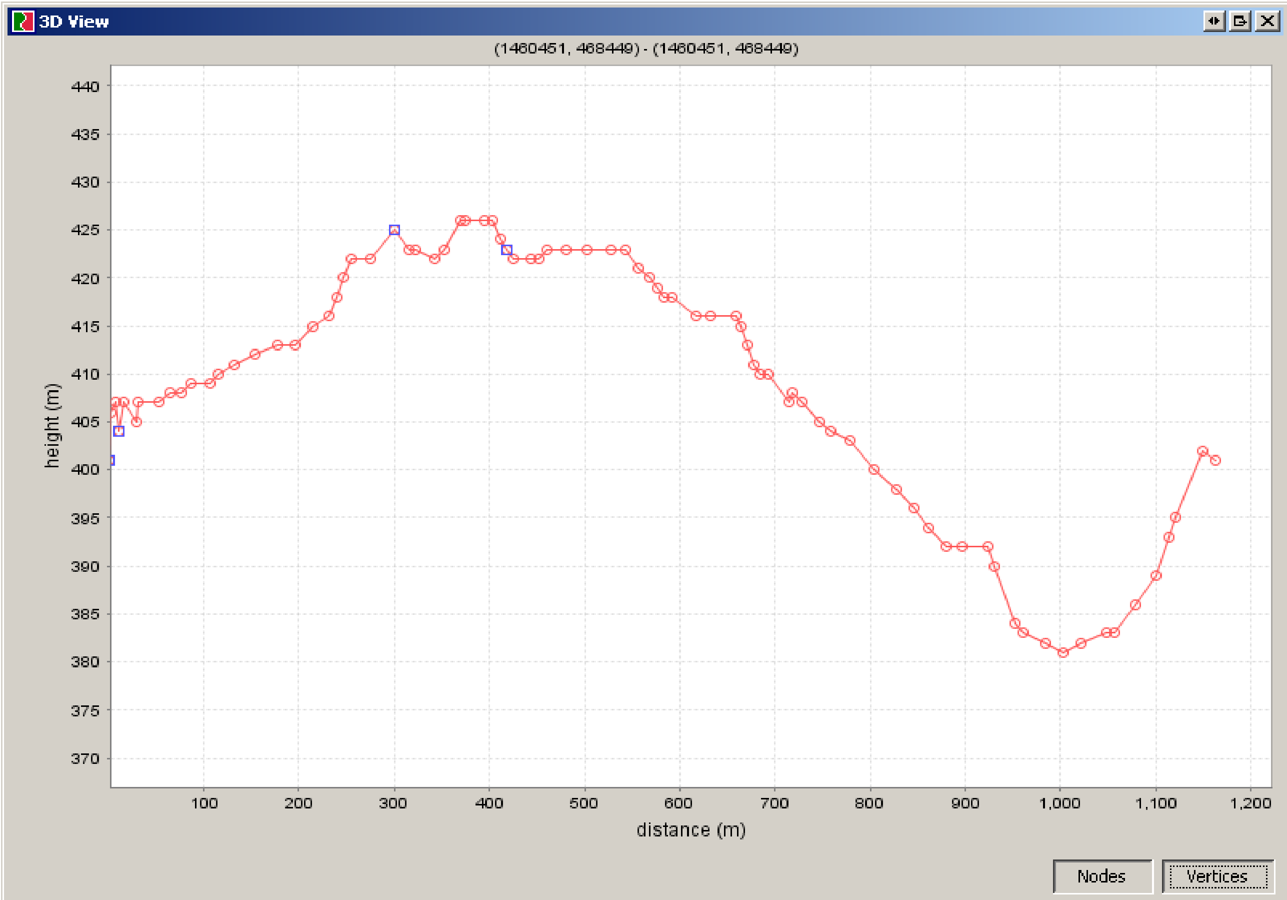


Figure 30: Small lake profile

WATERSHED BOUNDARY EDGES PROCESSING

The original TRIM TIN contains large "sink" errors. These artificial sinks affect any watershed boundary lines that are draped near these points (as well as other features). The streams will be fixed through the smoothing process, but the watershed boundaries will not.

[Recommendation] We do not feel that this is as important as the processing of the other FWA features; thus we currently recommend to not compute refined elevation on watershed boundary lines. This data can be added at a later date if required.

Other options include:

- Re-drape the watersheds boundaries using a cleaned-up TIN (including the smoothed stream lines)