Regional Geochemical Survey: Validation and Refitting of Stream Sample Locations

by Y. Cui

KEYWORDS: spatial data quality, regional geochemical survey, RGS, sample locations, refitting, catchment basins

INTRODUCTION

It is a common and challenging task to refit or adjust spatial data collected and geo-referenced on vintage hard copy topographic base maps at smaller scales, to more accurate digital topographic base maps at a much larger scale, in order to add value and advance the application of the spatial data.

A prerequisite of this task often involves the assessment or validation of the spatial data quality, and the need to manage and reduce the effects of uncertainty and error propagation. While spatial data quality is a topic that has been widely researched and published (*e.g.*, Goodchild, 1989; Guptill and Morrison, 1995; Shi *et al.*, 2002), it remains to be an issue to organizations that collect, integrate, disseminate and publish spatial data.

This paper summarizes recent work at the British Columbia Geological Survey (BCGS) in data quality assurance, data refitting and the results of the refitted Regional Geochemical Survey (RGS) stream sample sites in the province of British Columbia. The goal of the exercise is to develop an automated, practical and re-usable methodology based on a set of criteria and algorithms that computation can be performed within a spatial database environment. Highly uncertain sites will still require manual verification using high resolution imagery, large scale topographic maps and scanned paper maps. A brief summary is also provided on the preliminary results of adjusting the RGS stream sample sites from the streams on the original paper based National Topographic System (NTS) maps, to their equivalent or matching 1:20 000 scale streams from Terrain Resource Information Management (TRIM). The methodology and cases presented in this paper can be used as a guide to future efforts in validation of RGS stream sample sites.

This publication is also available, free of charge, as colour digital files in Adobe Acrobat® PDF format from the BC Ministry of Forests, Mines and Lands website at http://www.empr.gov.bc.ca/Mining/Geoscience/PublicationsCatalogue/Fieldwork.

The RGS program started in the 1970s and represents an investment of over $20 million in collecting and analysing over 60 000 stream sediment, moss, and lake sediment and water samples covering approximately 75% of British Columbia. The published RGS datasets contain analytical determinations for up to 50 elements, field observations and sample location information, which have been widely used in mineral exploration, land use planning, public health, and many other areas.

While the sample site location criteria are recognized as some of the most important aspects for the success of the RGS program (Ballantyne, 1991), the positional accuracy or data quality for the RGS sample locations has not been formally established or specified, partially due to the fact that the RGS program started as a geochemical survey of stream sediments at a reconnaissance scale to identify regions with a high mineral potential. As such positional accuracy of stream sample sites was not deemed as a concern.

The requirements of validating RGS data quality, especially positional accuracy of the stream sample locations, are largely driven by the applications of the RGS geochemical results in mineral exploration, through more detailed geochemical modelling and levelling.

Catchment basins of stream geochemical survey sites are recognized as being more effective to advance the levelling, interpretation, application and presentation of the geochemical results (*e.g.*, Bonham-Carter and Goodfellow, 1986; Bonham-Carter *et al.*, 1987; Hawkes, 1976; Jackaman and Matysek, 1995; Matysek and Jackaman,1995; Matysek and Jackaman, 1996; Sibbick, 1994; Sleath and Fletcher, 1982). BCGS has developed a fully automated algorithm to delineate catchment basins with high performance (Cui *et al.*, 2009). In order to use the most recent and detailed heights of land as the base of the catchment basins, it is required that RGS stream sample sites are validated and adjusted (or refitted) to the streams from the TRIM topographic base maps at a scale of 1:20 000. The confidence level of the RGS stream sample locations not only help to delineate catchment basins properly, but they also help to constrain the interpretation of the geochemical anomalies based on catchment basin analysis.

DATA SOURCES

Regional Geochemical Survey Sample Location Data

The RGS data includes more than 60 000 sample locations, field observations and analytical results for up to 50 elements for water, stream and lake sediment samples collected over a period of 30 years. Of the RGS samples, more than 52 000 were stream sediment and water sample sites.

The locations of the stream sample sites were measured on NTS paper-based maps at a scale of 1:250 000 and later more commonly at a scale of 1:50 000. The NTS maps were based on the NAD27 datum and have not been updated since publication. In recent years, the sample sites have been located with the aid of handheld GPS devices.

The selection method of RGS stream sample sites was based on Garrett *et al.* (1980), Ballantyne (1991) and refined by BCGS (Lett and Jackaman, 2004; Lett, 2005), which includes some of the following criteria:

- a regional survey with an average sample density of 1 sample per 13 square kilometres (km^2);
- active flowing first or second order streams that have a drainage basin area between 2 and 15 km^2 (first order streams will only generally be sampled for more detailed surveys, *e.g.*, 1 sample/5 km^2);
- within the active stream channel (subject to annual flooding);
- approximately 60 metres upstream from sources of possible contamination;
- approximately 60 metres upstream from a confluence;
- approximately 60 metres upstream from a high tide mark;
- upstream from lakes, ponds and marshes;
- prefer streams containing abundant fine-grained sediment (silts and clays) that have clean flowing water; and
- avoid very high or very low energy sites if possible.

The NTS paper maps at a scale of 1:50 000 are used as the Master Sample Location Maps to plan the traverse of the survey area, for identifying proposed sample collection sites. The sample collection crews use field copies of the paper maps as the Traverse Field Maps to record the actual sample sites, which may be different from the proposed location. The locations are transferred to the Master Sample Location Maps at the end of each day.

Further to potential uncertainty in identifying and marking the sample locations properly on the paper maps, the validation of the sample locations is also pertinent due to uncertainties from changes of geo-referencing sources and datum over the last 30 years and potential errors introduced from data transcription and transformation.

1:50 000 NTS Maps

While 1:250 000 NTS paper maps were used to locate some of RGS samples, the majority of the RGS samples were located on the 1:50 000 NTS maps. In addition to the available hard copy of paper based maps, a digital representation of the 1:50 000 NTS stream layer is used in this project. This dataset is also known as the "blueline" streams. In total, there are over 1 million stream network edges. Non-geometric attributes for this stream network include a hydrographical feature code, stream order, stream magnitude and a new watershed code which cross-references hydrographical features between the streams based on TRIM at a scale of 1:20 000 and the NTS 1:50 000 streams.

1:20 000 TRIM I Stream Data

For this project, the stream network and watersheds derived from the 1:20 000 scale TRIM I topographic base are considered as the provincial standard hydrographical base. The stream network has full connectivity by adding 'skeleton' network edges or connectors through water bodies such as lakes, rivers and canals digitized as polygons. In total, there are approximately 5 million stream network edges and over 3 million watershed polygons. Stream data collected through TRIM II and updates from the TRIM data exchange program are not included.

The stream network's non-geometric attributes are identical to the 50k stream attributes, except that they include a hierarchical key that was introduced to enable upstream and downstream queries in a non-spatial manner. The hierarchical keys were computed as the proportional distance along a stream where a child stream flows into its parent.

There is a stream cross-reference table (XREF_20K_50K_STREAMS) that lists the 50k stream edges and their equivalent or matching TRIM I stream edges. This table is used both in locating the matching TRIM I streams and in assessing data quality.

External Data Sources

For manual verification and visual inspection, high resolution imagery (*e.g.*, orthophotography) and more detailed topographic base map (*e.g.*, TRIM II streams) from external web services are accessed as WMS layers.

METHODOLOGY

Principles

This exercise is to develop a practical and re-usable methodology with the goal of validating the source data and reducing the uncertainty in the positional accuracy of the sample locations. The procedures based on this methodology will also be used to refit or adjust the sample locations to the matching TRIM streams.

Throughout the process, the positional uncertainty of the original sample locations is assessed, leading to the ranking and the development of confidence levels that can be assigned to each of the sites after the adjustment to TRIM I streams is completed.

Processing Environment

To ensure re-usability of the procedure, the prototyping, data analysis and processing are carried out in a fully interoperable environment consisting of desktop GIS, GeoWeb and Web-based batch processing services connecting to spatial databases that support Open Geospatial Consortium (OGC) Simple Features Specification.

Microsoft SQL Server® 2008 and PostgreSQL/PostGIS are used to store and query RGS and hydrographic data.

To visualize and edit specific sample sites in the context of the 50k NTS streams and 20k TRIM streams anywhere in the province, all data has to be served up dynamically by a bounding box to handle the huge data volume (over 9 million of hydrographic data alone). Two free and open source desktop GIS packages, OpenJUMP and Quantum GIS, are used to directly query and visualize the over 9 million records of 50k NTS streams, 20k TRIM I streams and watersheds stored in a Postgres/PostGIS database. This high performance visualization is achieved through the use of the viewing and panning screen as a bounding box to dynamically and efficiently load the spatial data from a PostGIS databases.

Web-based batch processing services are enabled by JEQL, a query tool with enhancement to SQL and full access to spatial functions available from JTS Topology Suite.

Google Earth® and OpenJUMP are used to access imagery and detailed topographic base maps served up as WMS layers.

PROCEDURES

Through prototyping and testing, the refitting procedure is developed and refined with three major steps. A simplified view of the procedure is depicted in a flow-chart (Figure 1).

During the test period, a set of criteria is developed to determine and assign confidence level to the refitting results (Table 1).

Step 1: Selecting 50k Streams Nearest to the RGS Sample Sites

This step is taken to determine if a given RGS sample site can be located on an NTS 50k stream within a reasonable distance or tolerance, as a way to assess the positional uncertainty.

The “nearest” algorithm is used to calculate the distances between a given RGS sample site and the 50k streams within a given tolerance. The nearest stream is selected with the shortest distance and constrained by stream code and stream orders. The constraint on stream code is to avoid selecting stream edges that are part of the stream network but not appropriate as sample locations, *e.g.*, a construction line through a lake. The constraint on stream orders is to ensure that the selected 50k stream is appropriate with a stream order specified by the RGS sampling guide (*i.e.*, first or second order), and matching the actual stream order recorded in the RGS field data.

A tolerance of 300 metres is used arbitrarily after consideration of uncertainties in estimating coordinates from a paper map at a scale of 1:50 000, potential positional drift due to a conversion between NAD27 to NAD83, and rounding errors. To put it in perspective, the size of a pencil circle marked as a sample site on the 50k paper maps is 150 metres. The tolerance can and should be adjusted so a practical number of sites deemed as highly uncertain can be manually inspected.

Step 2: Selecting TRIM I Streams Nearest to the RGS Sample Sites

This step consists of three different passes to select the matching or nearest TRIM I stream for a given RGS sample site.

In the first pass, the 50k streams identified for the RGS sample sites from Step 1 are used to select their equivalent or matching TRIM I streams through the stream cross-reference table (XREF_20K_50K_STREAMS).

In the second pass, a query is executed to select the TRIM I streams for the stream sample sites that are on or near the 50k streams as identified from Step 1 but they do not have matching or equivalent TRIM I streams based on the cross-reference table (XREF_20K_50K_STREAMS).

In the third pass, a query is performed to locate TRIM I streams within a radius of 150 metres and the nearest stream is selected for the stream sample sites not near any 50k streams within 300 metres.

Visual inspection is required for stream sample sites that are not near any 50k stream within 300 metres or near any TRIM I stream within 150 metres. Visual inspection is carried out on 50k paper maps (if available), TRIM II stream and orthophotography as WMS layers.

In the above three passes, the selection of TRIM I streams is constrained by the TRIM I stream order and the stream order recorded in the RGS field data. The TRIM I stream order must be the same or slightly higher than the matched 50k stream orders or the stream orders recorded in the RGS field data, due to the differences between mapping at scales of 1:20 000 and 1:50 000. Manual review is required if the stream orders are not equivalent

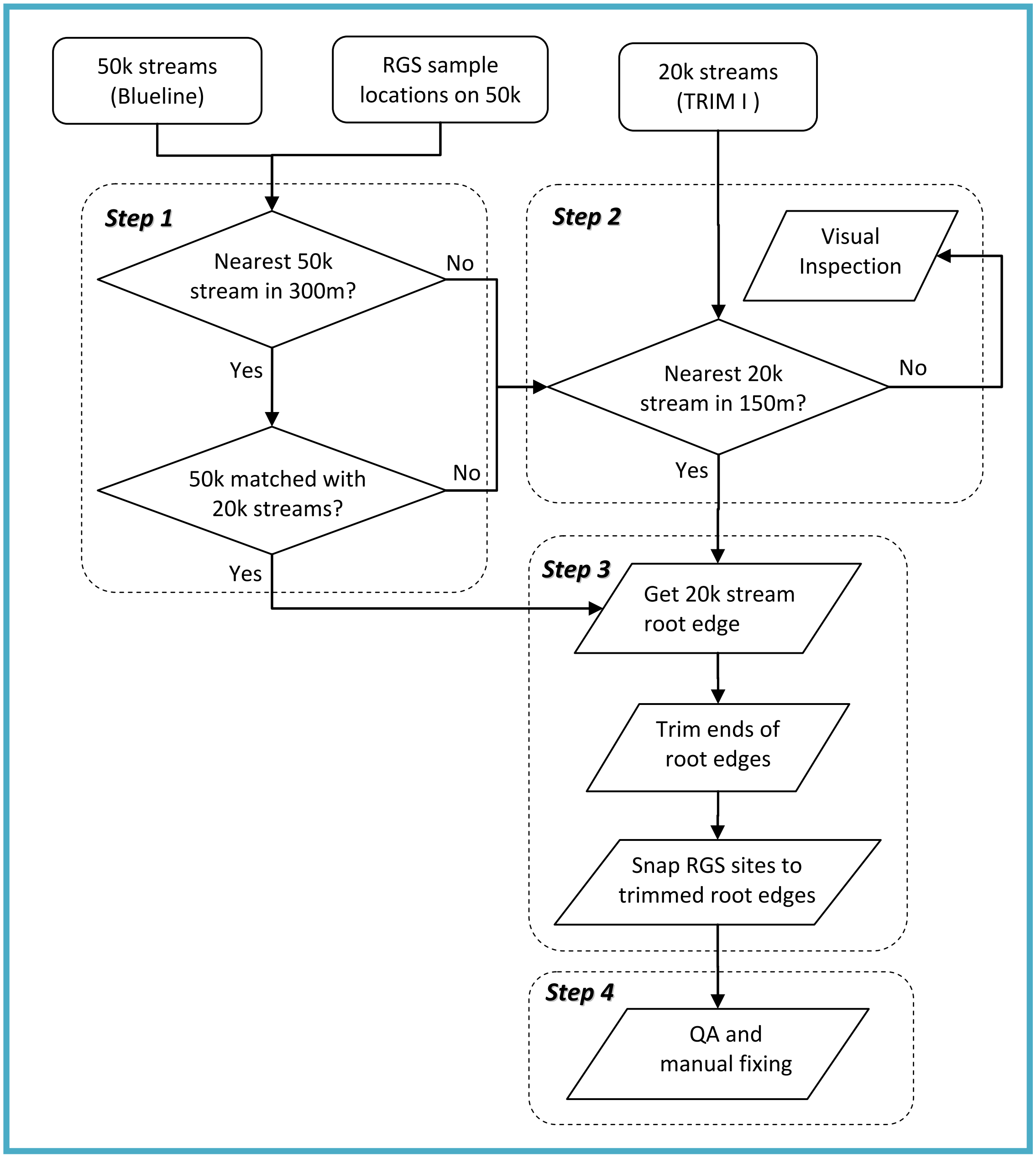

Figure 1. A simplified flow-chart of validation and refitting process.

between the selected TRIM I streams and the 50k streams or the RGS field data.

Some other constraints are placed on the TRIM I stream data to avoid selecting stream edges that are deemed not appropriate as the sample locations, *e.g.*, a construction line linking the main flow to a side channel. This is achieved by filtering them out based on spatial and non-spatial attributes.

The positional uncertainty of a site is assessed based on its distances to the nearest 50k stream and TRIM stream, if there is a match between the nearest 50k stream and nearest TRIM stream, and if the TRIM stream order matches the stream order recorded in the RGS field data.

The selected TRIM I streams are tested if they are located in the same 20k watersheds derived from TRIM I that contain the original RGS stream sample sites. This is carried out by spatial overlay between the 20k watershed polygons and the original RGS stream sample sites as points and the matched TRIM I streams as drainage lineStrings.

For a given sample site if there is no matching TRIM I stream, it is visually reviewed on the NTS 50k paper maps that were used in the field (if available) and then verified with the aid of TRIM II streams and high resolution images.

Table 1. Criteria for confidence level of validation and refitting results.

Confidence Level	Criteria
5	• Located on or near a 50k stream within 150 metres • A match between the nearest 50k and TRIM stream • Adjusted to the nearest TRIM stream within 150 metres with an equivalent stream order as the one from the RGS field data • Same resulting catchment basin after the adjustment of sample location
4	• Located on or near a 50k stream within 200 metres • A match between the nearest 50k stream and TRIM stream • Adjusted to a TRIM stream that is not the nearest but still within 200 metres with an equivalent stream order as the one from the RGS field data • Same resulting catchment basin after the adjustment of sample location or different catchment basin but the adjustment distance is less than 150 metres.
3	• Located on or near a 50k stream within 300 metres • No match between the nearest 50k stream and TRIM stream • Adjusted to a TRIM stream that may not be the nearest but still within 150 metres with the same stream order as or slightly higher than the stream order from the RGS field data • Different resulting catchment basin after the adjustment of sample location
2	• Located on or near a 50k stream over 300 metres • Not matched between the nearest 50k stream and TRIM stream • Adjusted to a TRIM stream over 150 metres • Different resulting catchment basin after the adjustment of the sample location to TRIM stream
1	• Location highly uncertain even after review and verification on other data sources • Adjustment distance is greater than 300 metres • Different resulting catchment basin after the adjustment of sample location
0	• No 50k or TRIM streams within 300 metres • Manual inspection unable to resolve a reasonable location • Adjustment is not applied: site left at its original location

Step 3: Adjusting RGS Sample Sites to the Matched TRIM Streams

The automated process to adjust or "snap" the original locations of the RGS stream sample sites to their matched TRIM I streams is carried out in a spatial database. When a matched TRIM I stream is identified as the best candidate for a given stream sample site, the stream is selected from the database. The lineString of the selected stream is trimmed for 1 metre at the ends, to prevent potentially snapping a sample site to a confluence with multiple up stream edges, thus ambiguity in upstream query and in conflict with the RGS guide of selecting sample sites 60 metres above a confluence. The adjustment of the stream sample sites to the trimmed TRIM I streams is carried out with the nearest algorithm that is executed in a spatial database.

Manual adjustment is carried out in a desktop GIS for stream sample sites that are located on TRIM II streams as identified by visual inspection or manual checking in Step 2.

Step 4: Quality Assurance and Manual Fixing

The final step is to sort the results based on their confidence level and manually check the results with the assistance of TRIM II streams, digital elevation models, high resolution orthophotography and other sources of information. Manual inspection and correction are carried out where results are considered incorrect or at a low confidence level.

DISCUSSIONS OF RESULTS

Summary of the Original RGS Stream Sample Sites

Stream order for a sample site is useful in resolving the ambiguity of a sample location (*e.g.*, a sample site between two streams of different stream orders), in conjunction with other data collected in the field such as stream width and depth.

In the RGS field data, stream orders are unknown for 8% of the stream sample sites that were mostly collected in 1976.

For the sample sites that stream orders were identified in the field, 53% of them are located on first or second order streams, 16% are on third order streams and 23% are on fourth order streams, and one of the sample sites is on a fifth order stream. Contradictory to what was stated in the RGS stream sample guide, 39% of the stream samples were collected on streams with streams order 3 and 4.

It is also discovered that even though the 50k NTS paper maps were used in the planning of sample site selection and locating of the actual sample sites in the field, there are sample sites that were collected at locations where streams were not mapped on the 50k NTS maps (Figure 2). Occasionally, streams were sketched by pencil on the paper maps.

Summary of Adjustment Results for Recent QUEST South Stream Sample Sites

The application of a simplified validation and refitting procedure yielded results with high confidence (Cui, 2010) to the recent infill stream samples from the QUEST South regional geochemical studies in 2009 (Jackaman, 2010). Out of the 785 sample sites, over 95% of them are automatically adjusted to the matching TRIM streams with high confidence after extensive manual review of the sites initially deemed as low confidence. Less than 5% of the sites are not near any TRIM streams and they are left at their original locations after review by Steve Reichheld who conducted the field survey.

The success is also partially attributed to the use of handheld GPS devices to locate the sample sites. For 36 samples sites with locations not near streams mapped on 50k NTS, or TRIM, or visible on orthophotography, the followings are the possible explanations (S. Reichheld, personal communication):

1) streams are small, usually under one metre in width;
2) meandering streams which have widened or changed courses since they were mapped;
3) samples were taken from small tributary off a main stream that likely didn't exist or were not mapped; and
4) samples were taken further upstream in the drainage than the 50k line shows.

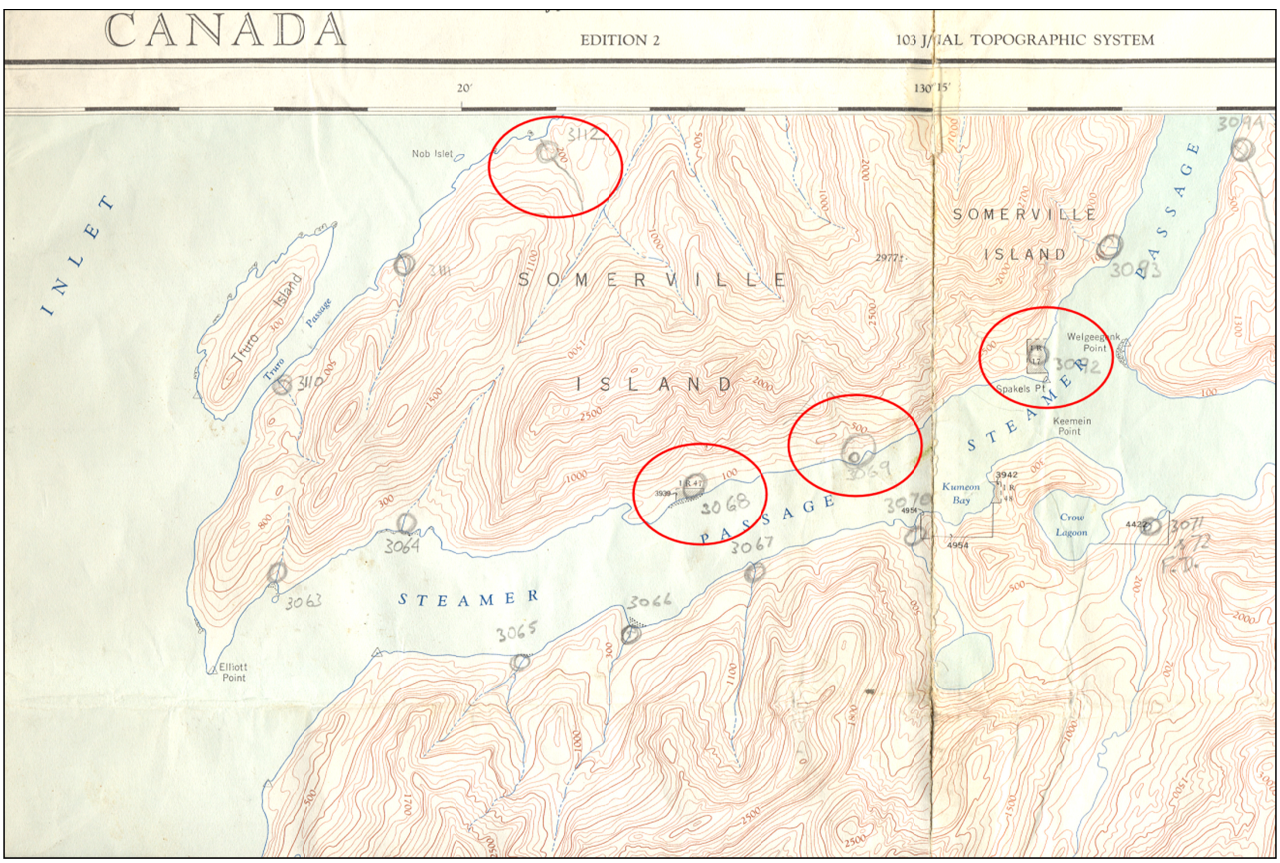

Figure 2. Examples of RGS stream samples collected on sites (in red circles) where 50k streams were not mapped on the 50 NTS paper map.

Summary of Adjustment Results for Stream Sample Sites Surveyed prior to 2008

The validation and refitting methodology has been applied to the RGS stream sample sites that were surveyed before 2008. A summary of the results follows the major steps in Figure 1, highlighting only the most common cases.

Sample sites located on 50k streams with matching TRIM streams

Among the RGS stream sample sites, 96% of them are located on or near 50k streams within a tolerance of 300 metres and 97% of the 50k streams for these sample sites have matching or equivalent TRIM streams. The automated adjustment of sample locations from the 50k streams to the TRIM streams is within 150 metres for 92% of the stream sample sites (Figure 3). However, 7% of the sites adjusted over 150 metres to the nearest matching TRIM streams. The cases assessed as highly uncertain (*e.g.*, over 200 metres) are visually inspected and manually adjusted if required, to ensure a high confidence level of the results (Figure 4).

The constraint on matching streams and equivalent stream orders is effective, as shown on Figure 5. Sample 92I813136 is closer to a third order TRIM stream flowing from the north which matches a first order 50k stream. However, the RGS field data indicates that this sample is collected on a fourth order stream, equivalent to the nearest third order 50k stream which matches the TRIM main stem (flowing from east) with a stream order of 5. With the constraints, this sample site is adjusted to the TRIM main stem with high confidence. In another case (Figure 6), the sample site (92H811428) is on a second order TRIM stream. The constraint on stream orders causes this sample site to be adjusted to a fourth order TRIM stream with acceptable confidence, because this sample was collected on a fourth order stream as recorded in the RGS field data.

The constraint on matching 50k streams and TIRM streams is also effective through the use of the cross-reference table (XREF_20K_50K_STREAMS) in resolving some of the ambiguities where a sample location can be adjusted to more than one TRIM stream. As shown on Figure 7, the 50k stream is closer to a TRIM stream to the west near the sample location (sample site 92G895273). The cross-reference table provides a match between the 50k stream and the TRIM stream to the east, causing the automated adjustment of the sample location to the TRIM stream on the east. However, it is worth pointing out that the cross-reference table should be treated as a reference source. If there is any concern on the result, the site should be visually inspected.

Sample sites located on 50k streams without matching TRIM streams

For the stream sample sites that are on or near 50k streams within a tolerance of 300 metres, 3% of the 50k

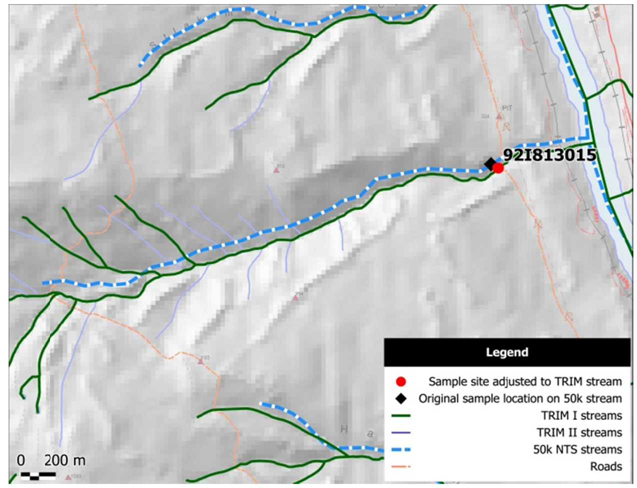

Figure 3. A case of high confidence on the sample location and adjustment result where a stream sample site (sample 92I813015) is located on a 50k stream within the tolerance and matched by a TRIM stream.

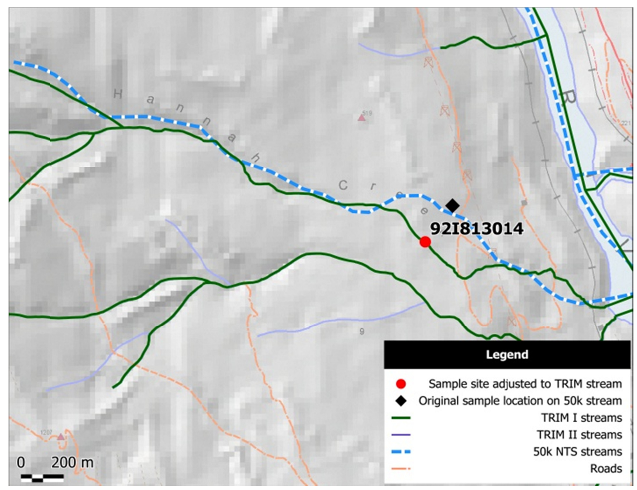

Figure 4. A case of acceptable confidence on the sample location and adjustment result where a stream sample site (sample 92I813014) is adjusted to a TRIM stream matching the 50k stream.

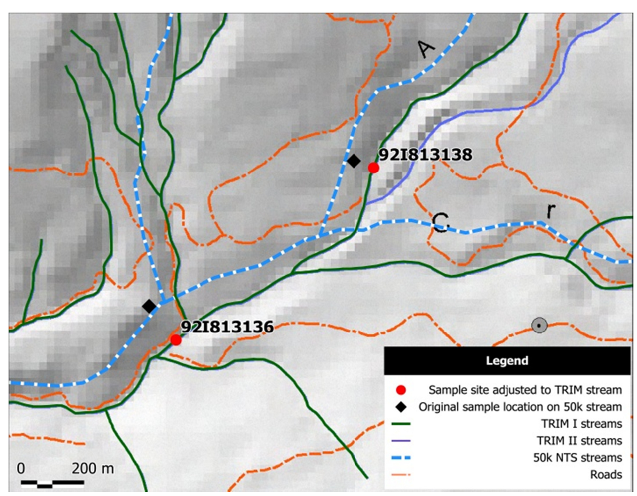

Figure 5. A case to show the effect of constraint on matching stream orders with high confidence.

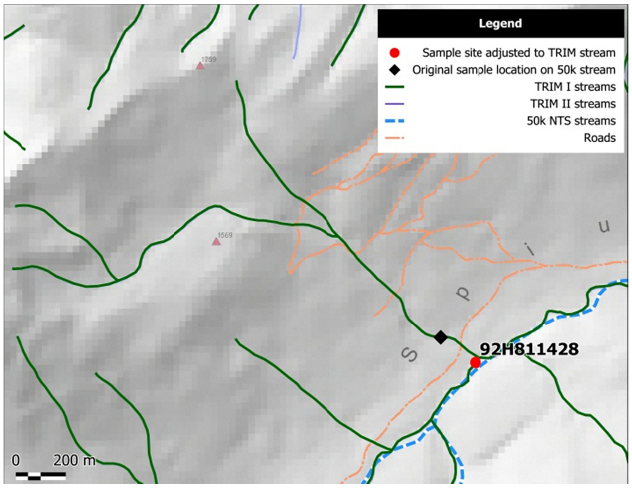

Figure 6. A case to show the effect of constraint on matching stream orders with acceptable confidence.

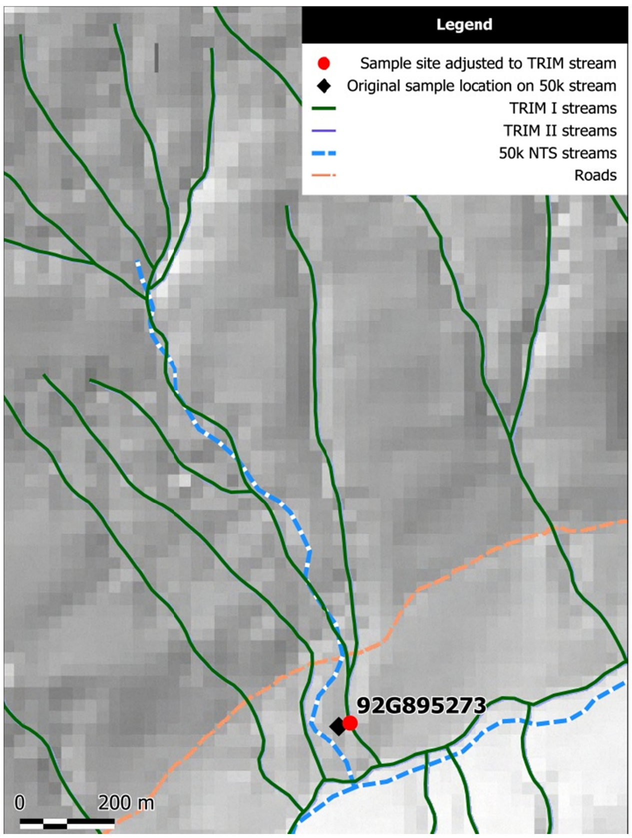

Figure 7. A case to show the effect of constraint on matching 50k streams with TRIM streams.

streams appear having no matching or equivalent TRIM streams using the cross-reference table XREF_20K_50K_STREAMS. In most cases, there are TRIM I streams within 150 metres of the stream sample sites. A 50k stream and a TRIM I stream are not matched usually because they have different upstream patterns (Figure 8). It is difficult to assign a confidence level to this kind of cases even after visual inspection.

When there is no TRIM I stream within 150 metres, the case should be inspected with the aid of the original 50k NTS paper maps, TRIM II streams and orthophotography. Some cases can be resolved by adjusting the sites to the nearest TRIM II streams with reasonable confidence (Figure 9). In other cases, the sites should be left at their original locations or adjusted to the nearest TRIM II streams with low confidence (Figure 10).

Sample sites not near 50k streams

For the 4% of the RGS stream sample sites that are not near any 50k stream within a tolerance of 300 metres, most of them are near TRIM I streams within 150 metres with an acceptable confidence level, typically as the case shown on Figure 11. A small number of stream sample sites are located on TRIM II streams (Figure 12).

In some cases there are TRIM streams near the sample sites but the results may not be acceptable. As shown in Figure 13, the field data indicates that sample 92J813009 was collected on a fourth order stream. However, the nearest TRIM II stream is order 1 and there is no fourth order stream within a reasonable distance.

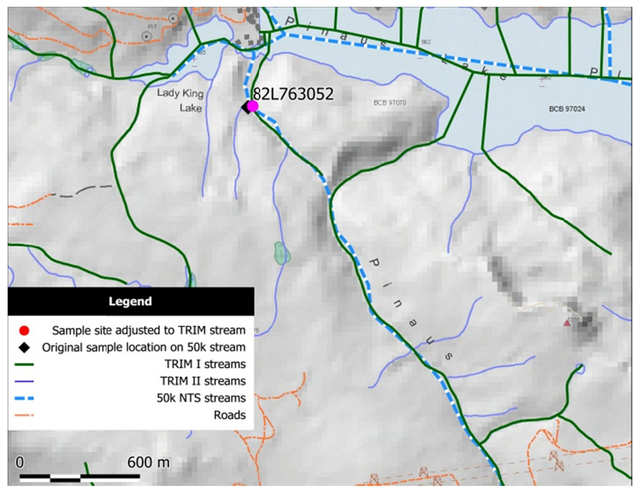

Figure 8. A case to show a stream sample site (82L763052) on a 50k stream that does not match the nearest TRIM I stream due to different upstream patterns.

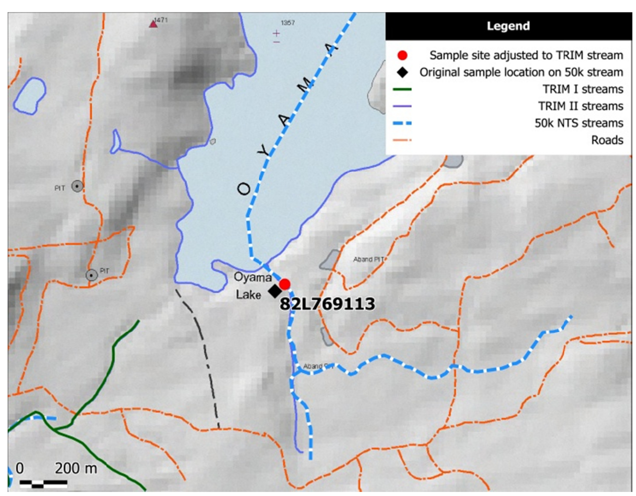

Figure 9. A case to show a stream sample site (82L769113) on a 50k stream that has no matching TRIM I stream mapped. This case is resolved by adjusting the site to a TRIM II stream.

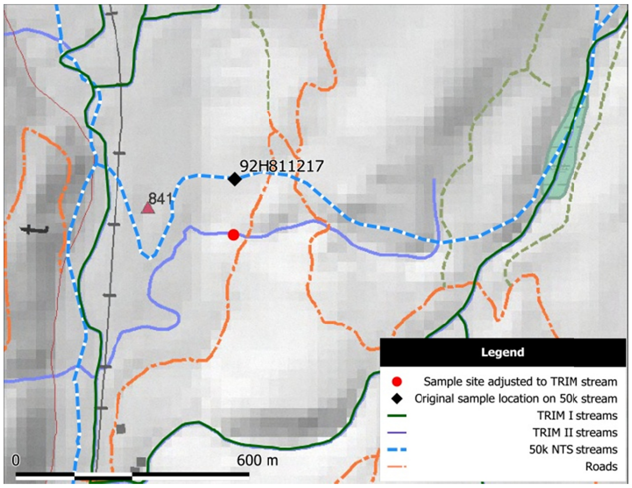

Figure 10. A case to show a stream sample site (92H811217) on a 50k stream that has no matching TRIM streams.

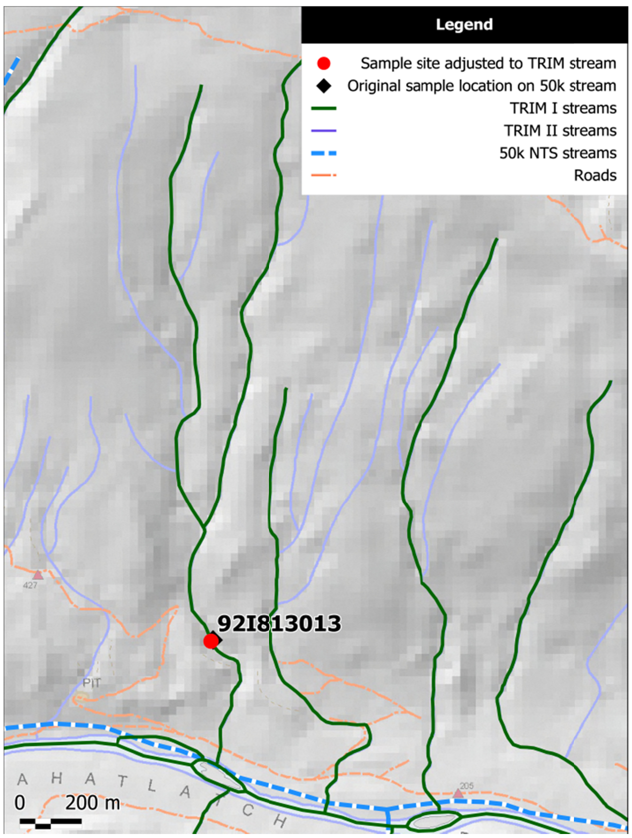

Figure 11. A case to show a stream sample site (92I813013) that is not near a 50k stream but is on a TRIM stream with acceptable confidence.

Only a small number of sites (1% of all the stream sample sites) are not near any streams. Some of the highly uncertain cases are shown on Figures 14 and 15.

One of the worst cases of location discrepancy is illustrated on Figures 16 and 17. Sample 92P793353 was collected on a fourth order stream based on the RGS field data (Figure 16). However, it is not near any 50k or TRIM stream with an order 4 or higher (Figure 16). An inspection of the hard copy 50k NTS map (Figure 16) indicates that the pencil sketch of the stream on the 50k NTS map for the sample site

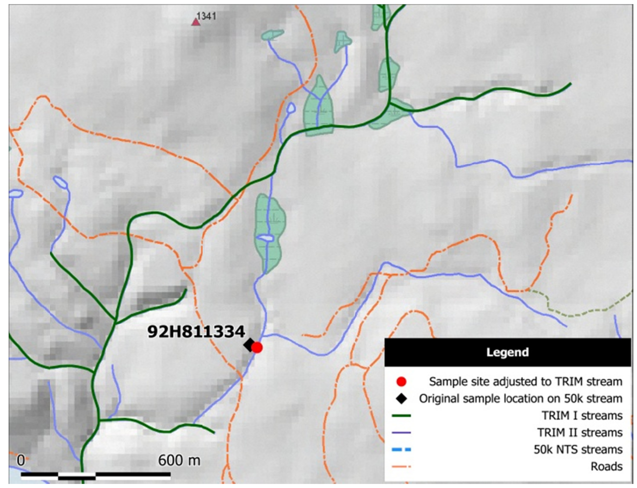

Figure 12. A case to show a stream sample site (92H811334) that is not near a 50k stream but is on a TRIM II stream with acceptable confidence.

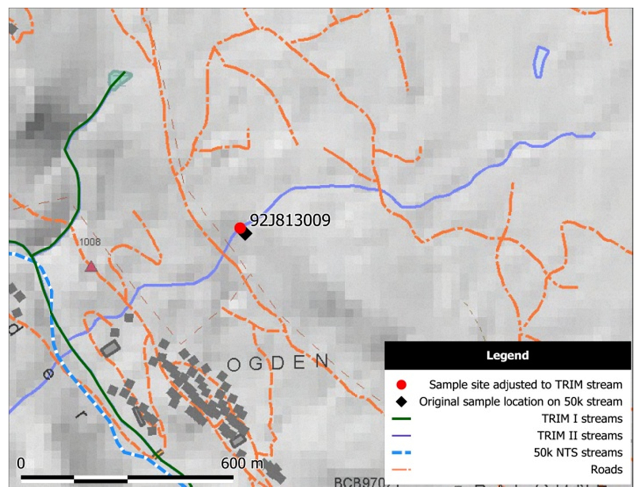

Figure 13. A case to show a stream sample site (92J813009) that is not near a 50k stream but is on a TRIM II stream with low confidence due to different stream orders between the TRIM II stream and the RGS field data.

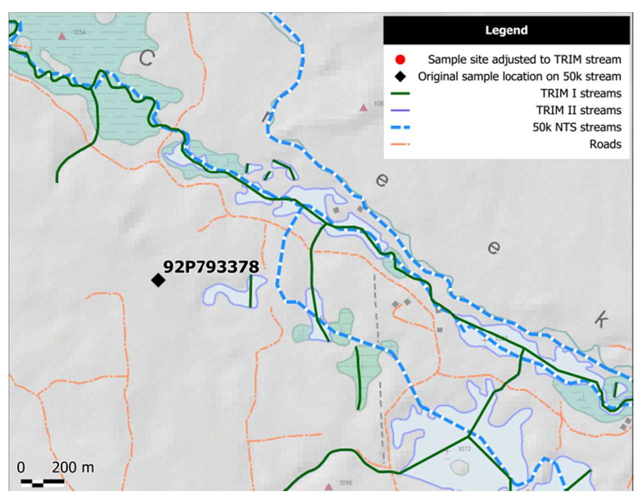

Figure 14. A case to show a stream sample site (92P793378) not near any streams.

matches a TRIM stream to the northeast of the sample site. If the location is adjusted to the matching TRIM

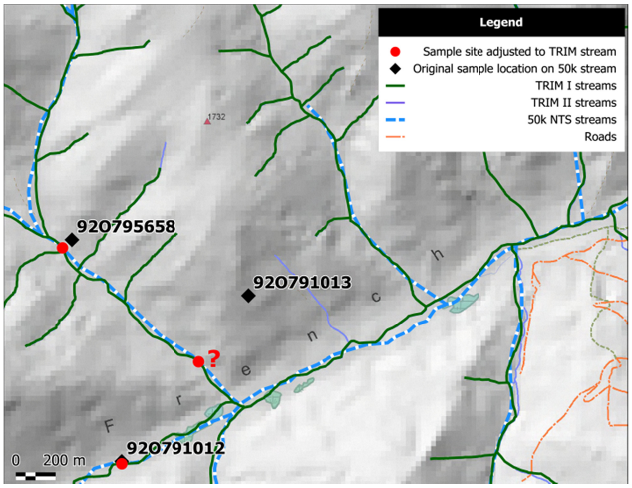

Figure 15. A case to show a stream sample site (92O791013) not near any streams.

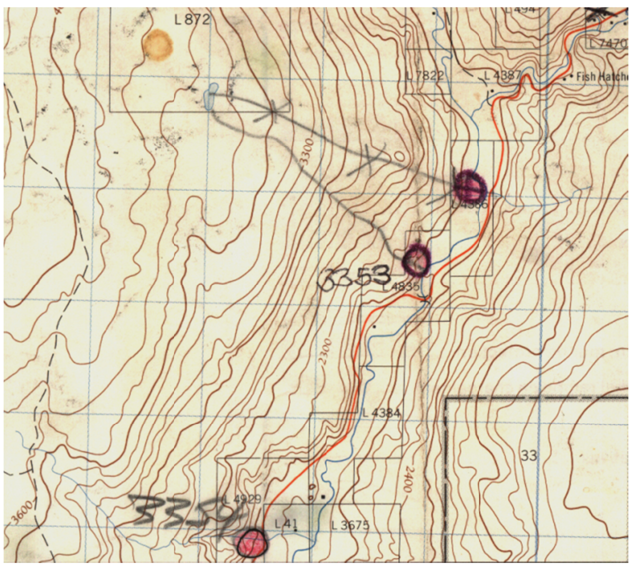

Figure 16. A stream sample site (3353) on a fourth order stream shown on the original 50k NTS paper map.

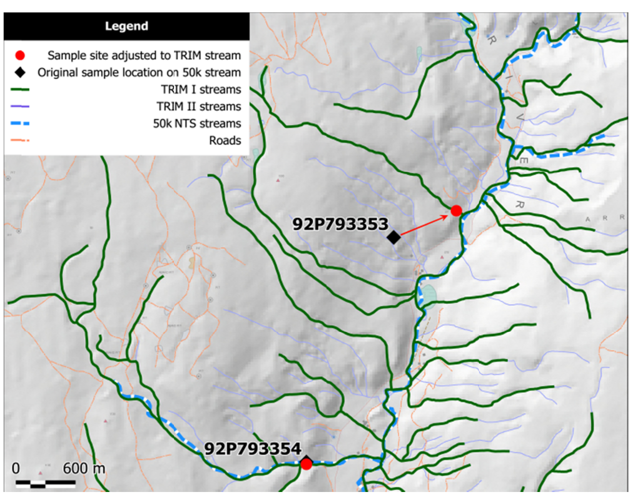

Figure 17. A stream sample site (92P793353, same as 3353 on Figure 16) that its location is off by over 600 metres from its original location as shown on Figure 16. The red arrow points to its original location.

stream (as shown by the red arrow), it represents a distance of over 680 metres. It is hoped that such case is an anomaly. Nevertheless it demonstrates that the location of the sample site could be off by over 600 metres.

Sources of Uncertainties

An attempt was made to document the sources of uncertainties. While an arbitrary confidence level can be assigned to a stream sample site based on the data quality criteria specified, the sources of uncertainties are not always obvious. As the case shown on Figures 16 and 17, it is difficult to speculate on the causes of the digital location off by over 600 metres away from the marked location on the paper map (Figure 16).

The validation on QUEST South stream sample sites and the cases documented so far for the pre-2008 stream sample sites shed some lights on the following sources of uncertainties:

- meandering streams which have widened or changed courses since they were mapped;
- samples were taken from small tributary off a main stream that were not mapped in 50k NTS or TRIM;
- different stream patterns between 50k streams and TRIM streams; and
- different definitions and field observations of stream orders in 50k streams, TRIM streams and RGS field data.

The following sources of uncertainties are possible but remain as a speculation pending further work:

- Data conversion between NAD27 and NAD83: difference up to 190 metres; and
- Errors in locations due to transcribing, conversion, or rounding.

Application of Results

The original locations of the RGS stream sample sites are suitable for geochemical modelling at a regional scale.

For more detailed analysis and geochemical modelling at finer granularity, the RGS stream sample sites should be validated and adjusted to the most detailed streams (*i.e.*, TRIM streams). This can be accomplished if the area is small enough by following and extending the methodology described in this paper.

Work is underway for future publication of a database of refitted RGS stream sample sites and updated catchment basins. Visual tools are also being developed for display in applications such as Google Earth.

ACKNOWLEDGMENTS

Ray Lett is thanked for sharing his knowledge and background information on the Regional Geochemical Survey program. Hailey Eckstrand assisted earlier effort on developing and testing the methodology. Aaron Chaput helped testing and inspecting some of the stream sample sites. Sophie Alexander from ioGlobal and Steve Reichheld reviewed some of the new stream sample sites in QUEST South. Discussions with Steve Reichheld are helpful on understanding the recent field survey. This manuscript benefited from a thorough review by Larry Jones and Pat Desjardins.

REFERENCES

Ballantyne, S.B. (1991): Stream geochemistry in the Canadian Cordillera: conventional and future applications for exploration; *in* Exploration Geochemistry Workshop, *Geological Survey of Canada*, Open File 2390, pages 6.1-6.74.

Bonham-Carter, G.F. and Goodfellow, W.D. (1986): Background correction to stream geochemical data using digitized drainage and geological maps: application to Selwyn Basin, Yukon and Northwest Territories; *Journal of Geochemical Exploration*, Volume 25, pages 139-155.

Bonham-Carter, G.F., Rogers, P.J. and Ellwood, D.J. (1987): Catchment basin analysis applied to surficial geochemical data, Cobequid Highlands, Nova Scotia; *Journal of Geochemical Exploration*, Volume 29, pages 259-278.

Cui, Y. (2010): QUEST South Regional Geochemical Survey: catchment basins for 2009 stream sample sites; *British Columbia Geological Survey* Geofile 2010-14, 4 pages.

Cui, Y., Eckstrand, H. and Lett, R. (2009): Regional Geochemical Survey: delineation of catchment basins for sample sites in British Columbia; *in* Geological Fieldwork 2008, *BC Ministry of Energy Mines and Petroleum Resources*, Paper 2009-1, pages 231-238.

Devillers, R. and Jeansoulin, R. (eds) (2006): Fundamentals of Spatial Data Quality; *Wiley-ISTE*, 309 pages.

Ehlschlaeger, C.R., Shortridge, A.M. and Goodchild, M.F. (1997): Visualizing spatial data uncertainty using animation; *Computers & Geosciences*, Volume 23, Issue 4, May 1997, pages 387-395.

Garrett, R.G., Kane, V.E. and Zeigler, R.K. (1980): The management and analysis of regional geochemical data. Journal of Geochemical Exploration, Volume 13, Numbers 2/3, pages 115-152.

Goodchild, M.F. and Gopal, S. (eds) (1989): Accuracy of Spatial Database; *Taylor and Francis*, Landon.

Guptill, S.C. and Morrison, J.L. (eds) (1995): Elements of spatial data quality (The International Cartographic Association); *Elsevier Science*, Oxford and Tarrytown NY, 202 pages.

Hawkes, H.E. (1976): The downstream dilution of stream sediment anomalies; *Journal of Geochemical Exploration*, Volume 6, pages 345-358.

Jackaman, W. (2010): QUEST South geochemical data, Southern British Columbia; *Geoscience BC* Report 2010-13, 153 pages.

Jackaman, W. and Balfour, J.S. (2007): QUEST project geochemistry: field surveys and data re-analysis (parts of NTS 093A, B, G, H, J, K, N, O), central British Columbia; *in* Geological Fieldwork 2006, *Geoscience BC,* Report 2007-1, pages 311-314.

Jackaman, W. and Matysek, P.F. (1995): British Columbia Regional Geochemical Survey – Nass River (NTS 103O/P); *BC Ministry of Energy, Mines and Petroleum Resources*, BC RGS 43.

Leggo, M.D. (1977): Contrasting geochemical expression of copper mineralization at Namosi, Fiji; *Journal of Geochemical Exploration*, Volume 8, pages 431-456.

Lett, R.E. (2005): The regional geochemical survey database on CD; *British Columbia Geological Survey* Geofile 2005-17; 8 pages.

Lett, R.E. and Jackaman, W. (2004): Stream geochemical survey guide; *British Columbia Geological Survey* Geofile 2004-07, 15 pages.

Massey, N.W.D. (1995): Geology and mineral resources of the Alberni – Nanaimo Lakes sheet, Vancouver Island, 92 F/1W, 92 F/2E and part of 92 F/7E; *BC Ministry of Energy, Mines and Petroleum Resources*, Paper 1992-2, 132 pages.

Matysek, P.F. and Jackaman, W. (1995): British Columbia Regional Geochemical Survey – Prince Rupert/Terrace (NTS 103I/J); *BC Ministry of Energy, Mines and Petroleum Resources*, BC RGS 42.

Matysek, P. and Jackaman, W. (1996): B.C. regional geochemical survey anomaly recognition, an example using catchment basin analysis (103I, 103J); *in* Geological Fieldwork 1995, *BC Ministry of Energy, Mines and Petroleum Resources*, Paper 1996-1, pages 185-190.

Shi, W.Z., Fisher, P.F. and Goodchild, M.F. (eds) (2002): Spatial Data Quality; *Taylor & Francis Group / CRC Press*, 2002, London and New York, 313 pages.

Shmoto, H. and Rye, R.O. (1979): Isotopes of sulfur and carbon; in Geochemistry of Hydrothermal Ore Deposits (Second Edition), Barnes, H.L., Editor, *John Wiley and Sons*, New York, pages 509-567.

Sibbick, S.J. (1994): Preliminary report on the application of catchment basin analysis to regional geochemical survey data, northern Vancouver Island (NTS 092L/03,04,05 and 06); *in* Geological Fieldwork 1993, *BC Ministry of Energy Mines and Petroleum Resources*, Paper 1994-1, pages 111-117.

Sleath, A.W. and Fletcher, W.K. (1982): Geochemical dispersion in a glacier melt-water stream, Purcell Mountains, B.C.; *in* Prospecting in areas of glaciated terrain 1982, *Canadian Institute Mining Metallurgy*, pages 195-203.