Module 5

GPS Surveying Procedures

5.1 Purpose

The purpose of this SHIM Module is to provide guidelines for field and office procedures, and data standards for watercourse mapping using Global Positioning System (GPS) technology. These guidelines apply to SHIM inventory but can be generally applied across many stream mapping projects.

GPS surveying is used extensively in the resource industry in British Columbia, especially in the forest industry where GPS technology has effectively replaced older methods such as tight-chain traverses for most tasks. There is much literature already available from agencies such as the Resources Inventory Committee (RIC), Geographic Data BC (GDBC), Ministry of Water, Land and Air Protection (MWLAP), and the Ministry of Forests (MoF) provide standards and approaches for GPS use for resource mapping. For example:

- Ministry of Forests Quality Assurance Procedures and Guidelines for GPS Surveys

The above source documents are referenced throughout this module.
5.2 Introduction

Stream mapping projects are typically carried out as a partnership of many agencies and organisations within a community. Personnel within these organisations will have varied skills, knowledge, and experience. It is recommended that all personnel, except perhaps field operators, read and understand this SHIM Module in its entirety. However, certain sections within SHIM Module 5 are intended for different team members acting in different capacities for the project.

- **Sections 5.3 and 5.4** are intended for project teams to make decisions on how to allocate resources, personnel, etc. on a stream-mapping project.

- **Section 5.5** provides an introduction to the information requirements for stream mapping, the advantages and limitations of using GPS for stream mapping, and provides practical scenarios for a stream-mapping project. Section 5.5 describes the project requirements in terms of personnel, training, and equipment.

- **Section 5.6** is intended for field personnel and others who must understand the different methods of capturing positional data in the field using GPS receivers. It describes different possible methods for capturing data for stream mapping. By knowing many different data capture methods, field operators can ensure they are using their time most efficiently. This section is intended only to supplement training and field experience, not to replace them.

- **Section 5.7** is intended for people who will be performing the GPS data processing. Contrary to popular belief, this is a fairly simple procedure and does not require in-depth knowledge of GPS. There is, however, a discussion on reference stations (including real-time correction) which should be understood by decision-makers.

- **Section 5.8** deals with issues of GPS data quality and integrating GPS data with data from other sources. It is intended for GIS technicians and people who will be making decisions about the quality of the GPS data. This section is intended only as a supplement to other training or experience in GIS or mapping software and especially in GPS data quality issues.

- **Section 5.9** discusses GPS data processing, including managing data using Pathfinder Office and ArcView software and editing GPS data.
using the GPS data dictionary tool extension for ArcView. This section is intended for people performing the GPS data processing.

- **Appendix A, C and D** contain the data dictionary, data standards and technical GPS requirements for stream mapping using GPS. Although most of the standards are contained in the main text, they are summarised in Appendix C due to their importance. Appendix C can be separated and attached to a contract or other instructions as well.

### 5.3 Urban Stream Mapping Program

#### 5.3.1 Stream Information Requirements

Accurate and reliable information is required to make practical, reasonable, and defensible land-use and environmental protection decisions about streams. Both positional and attribute information is required (Fig. 5.1).

Positional information provides the location and other geographical characteristics of a stream. The location of the stream's centreline in space allows users to:

- Plot the stream on maps, orthophotos, and other base maps.
- Compute physical parameters of a stream such as the length of a reach.
- Calculate distances to lot boundaries and other features affecting land-use decisions.
Attribute information provides the physical and biological characteristics of a stream (Fig. 5.2). For example, the bankfull width of a segment of the stream is a physical characteristic, and the nature of the riparian vegetation may be considered a biological (or habitat) characteristic. Combining attribute information with positional information allows users to:

- Calculate values and proportions such as the area of a riparian zone or the length of riffle habitat within a reach.
- Perform queries such as to display sections with gravel substrate downstream of a potential erosion site.
Figure 5.2: Attribute information for an example stream

Attribute information must be attached to a positional feature (e.g. a point or a line) to be effective. Attribute information is collected along with or separate from position information, depending on local requirements.

For example, if a municipality is interested only in the location of the stream centreline for zoning purposes, that basic information is sufficient for their needs. However, there is other information which should be collected as well such as the bankfull width (which defines the top of bank and is often more important for calculation of setbacks), and fish habitat information. This attribute information will be required for planning or habitat management. Although it is possible to collect only positional information, strong consideration must be given to collecting stream attributes.

5.3.2 Accuracy Requirements

The positional accuracy requirement for urban stream mapping is 5 metres, at 95% confidence. This means that features derived from a GPS survey (or any other means such as compass and chain surveys) must be within five metres of the true location of the feature, 95 percent of the time. This applies to such features as the centreline of a stream, and to reference points along that stream.
This level of accuracy is intended to be compatible with municipal mapping requirements to serve as a stream base map. **Note:** There are practical constraints on data collection in terms of the levels of accuracy and the costs of the survey (accuracy greater than 5 metres only comes at a much higher cost).

Most municipal mapping is compiled at a scale of 1:5,000 (one millimetre on the map equals five metres on the ground), or better. This implies that features on those maps will be accurate to at least 2.5 metres (measurable 0.5mm on a map scale). Many features in municipal mapping databases are much more accurate.

Stream locations, however, are often not nearly as accurate as the rest of the features in municipal and resource mapping (Fig. 2.1). Even though the planning (mapping) department may consider their data to be accurate to, say one-half metre, the consensus from people using stream data for planning and management is that five metre accuracy would be sufficient, and that seldom can they trust existing mapping to that level.

Although most GPS manufacturers claim sub-metre or 2–5 metre accuracy for their equipment and software, these are marketing claims and should not be taken seriously. In real-world conditions with local obstruction, tree cover, and other factors, five-metre accuracy is achievable only with the best GPS equipment and careful methods. Figure 5.3 is taken from recent scientific testing of different GPS receivers under forest canopy reported to be typical of conditions for most urban stream mapping in BC. The testing was conducted at the UBC Research Forest in Maple Ridge, BC.

![Figure 5.3 Global Positioning System (GPS) positional data collected under dense forest canopy](image)

Figure 5.3 Global Positioning System (GPS) positional data collected under dense forest canopy
This receiver performed the best among other GPS receivers and currently is one of two commercially available GPS receivers capable of 5-metre accuracy under dense forest canopy (SHIM Module 5, Section 5.5.3 provides equipment requirements and recommendations). These results indicate that five-metre accuracy is possible, with appropriate equipment and careful field and office methods. **Note:** Under difficult conditions, further interpreting or smoothing of the location provided by the GPS manufacturer’s software is almost always required. This interpretation process (deriving a best-fit line) is perhaps the most important factor affecting the quality of the final locations.

*Figure 5.4  Similar GPS receiver under identical conditions*

Figure 5.4 shows results from a different GPS receiver, similar in price, specifications, and target market to the receiver in Figure 5.3 (both are marketed as providing sub-metre accuracy). The test results were conducted under exactly similar forest conditions, satellite configuration, and weather. The second GPS receiver should be considered accurate to 10 metres, not to 5 metres. This results show a common problem with some GPS receivers, where the data is considered good (if the true location is not known), but is confounded with “systematic error”. These comparison demonstrate that GPS equipment must be chosen with care.

In order to ensure that the target accuracy is met, there are standard Quality Assurance (QA) and Quality Control (QC) procedures to be followed. Quality issues are discussed in Section 5.8.2, and in the Ministry of Forests’ QA Procedures.
5.4 Using GPS for Urban Stream Mapping

5.4.1 Advantages of GPS

Although differences do exist, GPS technology is considered to be the most accurate, reliable and productive means of capturing stream position information at present. GPS data can be stored on a field computer to capture standardised and complete attribute note (comment) information in the field.

Most urban streams have forest cover and it is very difficult to capture their location or characteristics from aerial photography. Most agencies use existing maps for stream assessment and have found that streams can be >10 metres in error. In some cases, vital tributaries, reaches, or entire streams are not mapped.

Producing accurate, reliable, and complete maps of urban streams is often possible only using GPS or other ground survey methods. With careful equipment choices, field procedures, and data analysis, accuracy of five metres or better is readily achieved, even under dense forest cover typical of coastal areas of British Columbia.

Corrected GPS positions are inherently geo-referenced, that is, they have global co-ordinates such as UTM (Universal Transverse Mercator). GPS data is easily and automatically integrated with other data such as municipal cadastral mapping, provincial resource mapping, and digital orthophotos using all common GIS and mapping programs. There is no requirement for time-consuming connections to local monuments or photo-identifiable points in the field.

Errors in conventional surveying methods (such as compass and tight-chain traverse) accumulate throughout the traverse as the survey progresses. Errors in GPS positions are independent and whether the survey is 10 metres or 10 kilometres, the error remains constrained to each data co-ordinate captured given the local conditions of GPS reception.

As well, conventional survey methods require crews of at least two people, with much starting, stopping, and note keeping and data entry. GPS methods require only one person – if a second person is needed for safety, that person can perform other tasks such as measuring cross sections or setting reference points. Extensive experience in the forest industry suggest that one person using GPS methods can survey twice as
much in the same time as with two people using conventional methods and it is almost always more accurate.

5.4.2 Limitations of GPS

The main limitation of GPS technology for stream mapping is that survey productivity and accuracy can be limited by local terrain / canopy conditions. Steep terrain and heavy forest cover can make GPS data capture slow due to reception of acceptable satellite coverage (see Appendix C for a discussion of the concept of coverage). Field methods such as offsets and fill-in traverses using conventional (compass and chain) methods can help productivity in difficult terrain conditions, although this adds a level of complexity to the field and office procedures, and potential error.

Position accuracy is often degraded in difficult terrain conditions, and in some cases may not meet accuracy standards and require re-surveying. Proper GPS equipment choices (see section 5.5.3) can help ensure sufficient accuracy, but this requires much more careful analysis and assessment of the corrected data.

Another major limitation of GPS technology is the fact that, although GPS data is inherently three-dimensional, the elevation is usually much less accurate (by a factor of 2 or 3) than the horizontal position. Elevations are often required for hydraulic and other engineering purposes. Usually the elevation accuracy requirement is actually greater than the horizontal requirement for these surveys.

5.4.3 Practical and Logistical Considerations

The primary practical consideration in using GPS for stream mapping is the cost of the equipment and the training required. Section 5.5.2 provides training recommendations and section 5.5.3 provides equipment recommendations and cost estimates. Section 5.1.4.4 suggests some strategies for reducing equipment and training costs.

Using GPS equipment also adds new logistical considerations, especially for remote projects. Some source of power is required to charge batteries and to download receivers nightly. Data should be corrected and analysed in the GIS program within a few days of collection, so some processing facilities should be available at remote project sites.
In difficult conditions with steep terrain and/or heavy forest cover, there are often times during the day where GPS reception is poor and these survey methods cannot work. Usually this means waiting for ten or twenty minutes (sometimes hours in extreme cases), but this may also slow down other work such as biological inventory. Careful pre-planning (see section 5.7.1. and 5.6.4.) can reduce the waiting time, and conventional methods can be used to supplement GPS methods during these reception “down” periods.

Stream mapping can be hazardous for personnel as well as expensive GPS equipment. The most robust receiver may not survive a drop into a pool or onto boulders. The antenna and cables can be quite difficult to manoeuvre through brush and debris in and around streams. Some equipment (see section 5.5.3) is not quite waterproof in rainforest conditions on the B.C. coast.

### 5.4.4 Stream Mapping Scenarios

As mentioned above (section 5.3.1.), both positional (the location and other geographical characteristics) and attribute (physical and biological characteristics) information are vital to stream mapping. The essential position information is the centreline of the stream, and the locations where attributes change along that stream. Although the centreline information can effectively stand alone, information about the physical and biological characteristics of that centreline must eventually be attached.

Capturing all this information in the field requires different equipment and expertise. Trained field personnel can easily learn how to operate GPS field equipment.

The most efficient strategy to capture the required stream information will vary depending on the local project and stream conditions. Factors such as budget, immediate and long-term information requirements, time constraints, availability of personnel, equipment resources, typical observing conditions, etc., should all be considered.

There are two basic scenarios to consider for stream mapping:

- Position and attribute information captured (1) **coincidentally** (at the same time).
- Position and attribute information captured (2) **separately** (in any order).

The first scenario is usually considered the conventional GPS survey method. However, it may not always be the most efficient use of equipment and personnel. As well, unless reference points are frequent, any subsequent update (for example after a catastrophic event) or extension (for example assessment of a new parameter such as pH observations not considered in the original survey) would require an entirely new survey (including GPS) of the section in question.

The second scenario is usually more flexible and may allow the most efficient use of resources. However, it does require better planning and efficient project management to ensure that effort is not duplicated.

During the first survey phase (which could be the GPS positional mapping, the attribute collection, a combination, or a reconnaissance phase), reference points along the stream are established. These can be existing, permanent points such as culverts, stream confluences, or any other uniquely identifiable location. Often, these would be markers (tags, blazes, etc.) established on streamside trees or other semi-permanent reference points. During the GPS survey phase, positions are obtained for these reference points and the centreline of the stream is surveyed at the same time.

When attributes are captured for the stream, all information is then referenced to these “reference” points. Since the stream centreline is known, only the distance (along the stream) from the reference points is required. The attribute is placed at a distance along the stream (downstream positive) from the reference point.
The following table summarises some of the advantages and disadvantages of capturing positions and attributes coincidentally or separately.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Coincident</td>
<td>conventional method, easy to explain to people</td>
<td>requires GPS equipment for all phases of project</td>
</tr>
<tr>
<td></td>
<td>can use GPS data collector for attribute data</td>
<td>not always most efficient use of personnel</td>
</tr>
<tr>
<td></td>
<td>project complete after one pass</td>
<td>field updates require entire re-survey of affected sections</td>
</tr>
<tr>
<td>(2) Separate</td>
<td>can allocate resources most efficiently</td>
<td>project management is more complex</td>
</tr>
<tr>
<td></td>
<td>can contract-out phases of project for maximum value</td>
<td>possibility that reference markers are lost between phases</td>
</tr>
<tr>
<td></td>
<td>reference markers established for future update or extension</td>
<td>requires at least two different passes during project</td>
</tr>
</tbody>
</table>

5.5 General Project Requirements

This section describes some of the GPS–specific requirements for a stream-mapping project. Individual stream mapping projects can vary in duration from a few weeks to many months or even years. They may involve just one person performing all aspects of a smaller project, or many different people, each with a specific task. A project may be carried out by a single organisation (such as a municipal department) or a broad-based community group composed of volunteers, professional consultants, and government support staff. Likewise, funding may be from many diverse sources, or a single continuing budget item.

Because of the widely varying possibilities, it is very difficult to make specific rules on personnel qualifications, training requirements, and equipment and software. For smaller projects, it may not be reasonable to purchase equipment and software and train personnel specifically for GPS, all for two week’s work.

This section is intended to give general guidelines on GPS project requirements including personnel, equipment and software, and GPS–specific training.
5.5.1 Personnel Requirements

For most watercourse mapping projects, the GPS survey component will be performed by existing personnel (e.g. fisheries technicians, GIS analysts, project managers). These people will usually have existing skills in watercourse assessment, although GPS surveying may be new to most people.

The following skills are required of personnel undertaking a SHIM stream mapping project:

**Field Operator**

A GPS field operator will perform the data capture in the field. This may involve just GPS work, or GPS work as well as stream assessment. If position and attribute information (see 5.3.1.) are to be captured coincidentally (see 5.4.4.), then field operators must be well versed in both GPS and stream assessment. Field operators must also, of course, be capable of working safely in a difficult environment.

**Data Processor**

The data processor will operate the GPS software. This includes downloading the receiver, downloading the reference station files (if required), differentially correcting the data, and exporting the data to the GIS/Mapping program being used.

Processing GPS data is perhaps the least technical task of all and requires very little training. It is usually a matter of executing a few commands and choosing a few files (some software is automated to the extent that only a single command is necessary). Many organisations have field operators or a clerk processing GPS data part-time and passing the data on to the Mapping Technician, where the important quality decisions are made.

**Mapping Technician**

The mapping technician will take the GPS data created by the data processor using the GPS software and create a final product. This is perhaps the most important step in the entire process as it is where decisions are made as to the quality of the GPS data.

A mapping technician must be well versed in the operation of the GIS or mapping software. Most importantly, they must have a thorough
understanding of the nature of errors in GPS data and how to best deal with these errors.

**Project Manager**

The project manager is the person (or group of people) making decisions about personnel, equipment, methods, etc. He or she is ultimately responsible for the quality of the data (positions and attributes). The project manager will supervise all other personnel on the project and choose the scenarios, equipment, and methods to be used.

Naturally, in many organisations one person may perform a number of these tasks. In some instances, tasks will be shared between people

**GPS Contractors**

Another option for watercourse mapping is to engage a GPS contractor to perform the GPS-specific aspects of the project. This would usually entail mapping the stream location and assessing the physical and biological characteristics of the stream separately (see section 5.4.4.), and having the contractor deliver a finished product (e.g. ArcView shapefiles) which will be immediately compatible with the overall project specifications.

Using a contractor for the GPS component of a project may often be the most productive and cost–effective way of mapping. Contractors will have GPS equipment and existing expertise in GPS surveying. By using a contractor, organisations and community groups do not have to acquire training and equipment, nor gain experience with the equipment and, especially, with the data interpretation. By contracting a segment of a project out, some costs are fixed and overall budgeting is more predictable. As well, complex GIS functions can be contracted out either to the same firm or a GIS specialist if required.

There are, of course, some disadvantages to contracting–out. Assessing the expertise of particular contractors can be difficult for project managers inexperienced in GPS surveying (contact the SHIM mapping committee for advice and recommendations if choosing contractors). Defining a standard format for data delivery and applying QA (Quality Assurance) procedures may be beyond the means of local groups.

By engaging a contractor, an organisation misses the opportunity to develop some in–house expertise in GPS surveys. Even though the first few projects may not be as productive as using a contractor, there are
often distinct benefits in suffering through the learning curve and becoming capable of performing GPS surveys on other projects.

### 5.5.2 Training and Experience Requirements

Training is one of the most important aspects of ensuring quality in the final mapping product for a SHIM project. This training includes all aspects of the project including GIS and GPS training.

Properly assessing the characteristics of a stream, and then managing the large amounts of spatial and attribute data require much training and experience. The GPS aspect of a stream-mapping project is probably the least complex. GPS technology can be considered just a tool to be used by personnel expert in other tasks, such as fisheries technologists or GIS analysts.

However, as for any other tool, some training is required to use GPS receivers in the field, to correct and properly manage the data, and to plan and manage projects involving GPS technology. The following are general recommendations for training for different personnel involved in a GPS project. They are not mandatory, and other training models may well be preferable in some instances.

In all cases, the SHIM mapping committee should be contacted for current recommendations on training, and for information on where to get the training.

**Training Recommendations – Supervisors and/or Mapping Technicians**

Supervisors should have an understanding of all aspects of GPS surveying from planning, through fieldwork, data processing, error handling, and data integration. They should also have some experience in those areas – experience is actually much more important than training.

Appropriate training is available from many sources, including a specific 4.5-day course developed for the Resources Inventory Committee. This course was developed specifically for under-canopy GPS work to the 10-metre accuracy standard. Unfortunately, the effectiveness of the course delivery varies with the experience and background of the instructor. Users should ensure that they get extensive practical guidance in understanding and dealing with GPS errors under forest canopy.
Of course, other training models such as courses in university or college, or on-the-job training are acceptable, especially when accompanied by experience. This training must be evaluated on the merits of each instance.

It is most important to realize that any training cannot be considered a substitute for actual experience, whereas practical experience can certainly be considered a substitute for formal training. It is difficult to specify certain levels of experience as projects and the person’s role in a project will differ greatly. In stream mapping projects, experience and knowledge of the physical and biological aspects of streams is much more important than experience and knowledge of GPS.

An overall project supervisor should be first and foremost familiar with stream assessment. However, somebody must be responsible for making decisions about GPS data quality. In many projects, the project supervisor will rely on a mapping technician to provide the expertise in GPS data quality, and field operators to advise on the most efficient data collection methods.

A good general rule would be that the person responsible for assessing data quality (and dealing with the data) must have significant supervisory experience (including some field experience) on at least one similar project involving GPS.

**Training Recommendations – Field Operators**

Field operators will need some training using the specific GPS equipment for the project. They also need to understand some of the basics of GPS, and how to effectively and accurately capture data under forest cover. Depending on the project, field operators may have to do their own mission planning and downloading as well. For projects where the stream assessment is carried out the same time as the mapping, field operators will usually be fisheries technicians who have learned to use GPS as a tool.

There are formal courses available for field operators, but these do not always meet the practical needs of a stream–mapping project. It is often preferable for field operators unfamiliar with GPS methods to learn on-the-job from experienced personnel – either other field operators, or a project supervisor or mapping technician with experience. As long as field operators have a basic conceptual understanding of how GPS works, experience in the field is the most important.
**Specific Training for Stream Mapping**

Some agencies are offering training specific to stream mapping with a GPS and a stream assessment component. Courses can also be set up as custom courses by experienced trainers, tailored for local needs. If available, such a course is preferable to a formal, GPS-only course for field operators.

The stream assessment portion of the course can be a short session intended to familiarize experienced fisheries technicians with the specific procedures and interpretations of stream characteristics for the project. It might also be a much longer session intended to train non-technicians (e.g. local fishers) in stream assessment procedures.

**5.5.3 GPS Equipment and Software**

There are many different GPS receivers available on the market. Depending on observing conditions and methods and the type of receiver, accuracy from approximately 25 metres to a few millimetres can be achieved.

Generally, there are three types of GPS receiver: Navigation-only (consumer-grade), differential GPS (resource mapping grade), and carrier-phase GPS (survey or geodetic-grade). Costs vary from less than $200 to about $50,000 per receiver, and for higher accuracy, multiple receivers are required. The appropriate receivers for stream mapping work (accuracy requirement 5m at 95% confidence) are in the resource mapping grade. These receivers can cost from $4000 up to $18,000 (Fall 2000).

Although there is quite a range of receivers in this class, not all receivers will meet the accuracy requirements in all conditions. Most (not all) of the resource-grade receivers will achieve 5m accuracy in ideal conditions. However, under difficult conditions (e.g. coastal forest cover), only a very few will meet the specification – unfortunately but understandably, these receivers are at the upper end of the cost spectrum.

**Minimum Equipment Requirements**

A GPS receiver–software combination to be used for stream mapping must meet the following minimum requirements:

- Must store data, which can be differentially corrected (including real-time correction). Un-corrected positions are not acceptable.
Must have configuration options so that all data meets the minimum conditions for each individual GPS fix:

- HDOP <5 or PDOP <8
- At least 4 satellites
- No satellites below 15 degrees elevation angle
- Must be capable of storing attribute information along with position information.

**Equipment Recommendations**

Although most resource mapping grade receivers meet the minimum equipment requirements above, very few can achieve 5 metre accuracy under forest cover. The only way to assess this is to rigorously test equipment under controlled conditions typical of the project area. This is a very complicated and expensive proposition, far beyond the means of most local organisations. Although most GPS manufacturers or distributors will provide proof of their equipment’s capabilities under difficult conditions, these claims have no credibility unless they have been performed absolutely independently, and follow rigorous scientific procedures.

An independent GPS consultant, along with a national forestry research agency, have established a rigorous GPS testing protocol and an extensive field test range at the UBC Research Forest in Maple Ridge, BC. To date (Fall 2000), 12 different receivers from 8 different manufacturers have been tested – only two receivers have met the 5 metre (95%) accuracy specification.

As of 2001, the report from this testing was undergoing review and is not yet available to the public. However, the salient results have been made available to members of the SHIM mapping committee, and the Ministry of Forests’ GPS Working Group. Results of future testing (as new equipment becomes available) will also be available to the committee.

Before using any GPS receiver on a stream-mapping project, SHIM committee members should be consulted. Sales staff, manufacturers, or even other users may not always be able to provide the best information to make an informed GPS purchase.
5.6 Field Methods For Stream Mapping

This section is intended for field personnel and others who must understand the different methods of capturing positional data in the field using GPS receivers. It is meant to stand alone as a reference for field operators as well as being an integral part of the entire GPS module of the *Sensitive Habitat Inventory Manual*. It contains an explanation of the different methods of data capture, and provides some practical advice on increasing accuracy and productivity, especially under forest canopy. It does not provide specific field procedures for stream mapping, but rather describes all of the methods available. It is up to field operators and their supervisors to decide which methods will work best in each circumstance.

Stream mapping is usually more complex than idealised GPS mapping projects as described in manufacturer’s tutorials and most literature and training available. The different mapping scenarios (described in section 5.4.4.), difficult observing conditions (e.g. forest cover and steep terrain), and variable physical conditions (e.g. high runoff, debris piles, and steep banks) mean that field operators must creatively use all methods and skills at their disposal.

It is assumed that field operators have had some basic training in using the specific GPS receiver system and that they understand some basic GPS concepts such as Dilution of Precision. This basic training is available from many sources (discussed in section 5.5.2.).

In this section, the different methods for capturing stream location information using GPS technology are discussed. The section is intended to supplement the training and experience that field operators may have by describing methods and strategies to deal with some of the unique requirements of stream mapping projects.
For urban stream mapping projects, a geographical feature such as a stream or a barrier usually has both positional and attribute information. Positional information describes where the feature is and its size and shape. Attribute information includes non-geographical information, which further describes the feature. Section 5.3.1. further explains this concept.

**Geographical Features**

There are three fundamental types of geographical feature: **points**, **lines**, and **polygons** (Fig. 5.6). Maps and GIS databases, which represent the ground, are composed of these three features. Using symbology (e.g. pattern, symbol, colour, line thickness), different attributes (e.g. stream classification, point type, ownership status) can be represented.

The methods used during a stream survey will vary depending on many different factors. The next two sections describe the various methods which can be used to survey point and line (and therefore area) features.
5.6.1 Methods for Point Features

Static Point Features

The static point is the most common method of capturing a point, and the only acceptable method under these Stream Mapping Specifications. To collect a static point feature using GPS equipment, the operator positions the antenna over the feature and logs a number of position fixes. These position fixes are later averaged to give a single position for the point (Fig. 5.7).

Field Specifications for Static Point Features

For standard static point features, occupation time must be at least 60 seconds AND there must be at least 15 individual position fixes for each feature.

The reason that there is both a minimum occupation time and a minimum number of fixes is the need to meet the accuracy requirements, yet still remain productive. Occupation time is the main factor affecting point accuracy (after about 10 minutes, there is no appreciable difference), as errors tend to average out over time. Sixty seconds is enough that there is some averaging effect, and that error trends can be recognised and dealt with in the mapping stage.
However, in poor terrain conditions (such as under forest canopy) it is often difficult to get 60 position fixes over a 60 second occupation. There are often not sufficient satellites available, and users must move the antenna around to get fixes. A minimum of 15 fixes is required so that there is enough information to give some reliable clues to the quality, even though occupation time is usually the main factor in accuracy.

Field operators should attempt to spread the 15 fixes over the 60 seconds as much as possible. A good procedure would be to begin counting the 60 seconds after the first position fix is recorded. If the receiver stops logging fixes, the operator moves the antenna around (within reason) or waits until it begins logging again. After both conditions (60 seconds AND 15 fixes) are met, operators can end the static point feature and move on.

**Point Offsets**

There are many instances where a point feature cannot be occupied directly. Either there is not enough GPS coverage around the point or the point is not accessible (for example, on the other side of a fast-flowing stream). In these cases, a point offset can be used. The point offset method is also used in the variable offset traverse method described in section 5.6.2.

For a point offset, a GPS point feature is collected wherever there is a convenient location (i.e. accessible and has a GPS signal) and a direction and distance (and perhaps slope) recorded to the actual point feature (Fig. 5.8). Some receivers allow operators to enter the offset information directly – however the information should also be written down in a field book, at least until the procedure is flawless. The biggest cause of errors in offsets and other non-standard data collection procedures is a misunderstanding between the field and the office, and clear field notes can be very valuable.
Field Specifications for Point Offsets

The maximum distance for point offsets is 25 metres. Directions must be accurate to 2 degrees and distances accurate to 1 metre. If the slope is over 10 percent and over 10 metres long, slope measurements (accurate to 5 percent or 3 degrees) must be made.

A compass is used for the direction – azimuth (full circle or 360°), but bearings (90° and a quadrant NE, SE, SW, or NW) are acceptable. The compass should read to at least 2° and all readings should be corrected for magnetic declination – the correction may be done in the field (e.g. setting declination on the compass bezel) or later in the office. Some receivers will accept magnetic bearings and convert them using an internal model.

Some GPS receivers actually have internal compasses, however these are seldom reliable even if they are the fluxgate type (a digital compass module). Internal compass displays should be carefully checked before use.

Distance measurement should be to the nearest metre. For very short distances, a careful estimate or pacing may be sufficient. For longer distances, crews should carry a thread chain or a fibreglass tape to measure distances. Care should be taken to ensure that the tape is free of all obstructions (e.g. branches) – known as clearing the chain or tight chaining.

Usually, distance measurements are taken along the slope of the ground. If that slope is significant (greater than 10%), the slope distance will be
greater than the actual map distance. If the distance is very short (less than 10 metres), the difference will be negligible in all but the most extreme slopes. If the line is long or the slope is significant, slope measurements must be taken. These should be accurate to at least 5% or \( \frac{3}{176} \), meaning that a separate clinometer is usually required (clinometers built into compasses are seldom accurate enough).

There are many small, light laser measuring devices available which can measure accurate distances to objects many metres away. Some of these units have a built-in compass and clinometer as well. Costs range from about $350 to over $10,000. The advantage of the laser is that longer distances can be measured without a second crew member to run out a tape. Points that are inaccessible (for example in a stream with heavy runoff) can also be measured easily. However, the digital compasses in laser instruments, although they usually measure bearings to fractions of a degree, are no more accurate than hand-held compasses since the magnetic declination often has local variations of two degrees or more.

### 5.6.2 Methods for Line Features

**Dynamic Line Feature**

The dynamic line is the most common method of surveying line features, although there are other acceptable methods. For a dynamic line survey, the operator moves the antenna along the line to be surveyed (usually a stream centreline). At programmable intervals (e.g. every second), the receiver logs a position fix, and those individual fixes are joined to create a continuous line.

![Figure 5.9: An example of a dynamic line feature](image-url)
Field Specifications for Dynamic Line Features

For all line (and polygon) features, all significant deflections and meanders of the feature must be mapped.

For line (and polygon) features surveyed in dynamic mode, the majority of the individual position fixes must be no more than 2.5 metres apart. The maximum distance (gap) between successive position fixes is 15 metres.

The accuracy of a dynamic line is naturally a function of the accuracy of the individual position fixes. Under difficult conditions, it is possible for the individual fixes to be quite a few metres in error at times. If the line is defined by very few fixes (e.g. one every 10 metres), a 10–20 metre error could easily go unnoticed. It is essential that enough fixes are collected so that these errors can be detected, even if those fixes are not strictly necessary to define the line. Field operators should strive to collect as much data as possible – although the specifications say 2.5 metres, even closer should not be considered excessive. The extra data can never hurt and it will help ensure that the most accurate line is generated during the mapping stages.

In some terrain conditions, like dense canopy or steep banks, there will be unavoidable gaps in the position fixes. Field operators should monitor when the receiver is logging and not logging data and ensure that the gaps are never exceed 15 metres. It is also very important that all significant deflections of the stream are captured (Fig. 5.10). If the stream bends, the operator must ensure that there are sufficient position fixes to define the deflection, even if the distance is less than 15 metres.

Figure 5.10 An example of surveying for dynamic line features for deflections and gaps in stream centres.

In many streams, logs, deep pools, and other features, can impose obstacles on surveying. Usually that means leaving the stream centreline to avoid any obstacle and a pause feature when data logging should be
used to detour any obstacle and resume centreline surveying. It is very important that field operators suspend logging whenever varying from the line being surveyed, for whatever reason.

![Diagram of detouring around an obstacle](image)

**Figure 5.11** An example using the **pause** feature to detour around an obstacle

It is also a good idea to suspend logging if the field operator will be in one place for more than 30 seconds. This will help later in data interpretation, and will help minimize significant errors in the GPS positions due to longer term multipath on a single fixed point or position.

**Constant Line Offsets**
Many GPS receivers allow operators to collect line features as constant offsets. In this case, the antenna is moved along a line, which is a certain constant distance from the true location of the line. This can be very useful in instances where it is not possible to walk down the actual line (for safety or other reasons). Unlike for point offsets, it is not possible to measure the offset all the way along the line, so the field operator must be diligent to keep the offset constant. Because the operator is continually estimating the offset distance (after an initial measurement), the offset distances should be kept small.

**Figure 5.12** An example of a *constant line offset*.  

<table>
<thead>
<tr>
<th>Lat 1</th>
<th>Lon 1</th>
<th>Hgt 1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lat n</td>
<td>Lon n</td>
<td>Hgt n</td>
</tr>
<tr>
<td>Attributes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Field Specifications for Constant Line Offsets**

The maximum distance for constant line offsets is 5 metres.

Constant line offsets may work in certain circumstances such as roads and other man–made features with a constant width. However, for typical stream surveys, a constant offset is seldom practical except for very short sections. Natural streams seldom are a constant width, and variations in terrain, vegetation, and lighting make it very difficult for operators to constantly estimate the offset. Often, walking along the banks is more difficult than actually walking in the stream due to scrambling over and around deadfall, riparian vegetation, pools and side channels, and so on.
One stream-mapping scenario where a constant offset line may be useful is for constricted channels such as drainage ditches. In these cases, there is usually a clearly defined channel width and it is usually not difficult to walk on or near to the bank of the channel. Often such channels are deeper than natural streams and an offset line may be the only way to safely survey them. However, constricted channels are often quite straight by design and a better way to survey them may be using point offsets at the deflections. They may also be completely visible on aerial photographs and thus accurately mapped already – it may be more efficient to use the existing maps for location and conventional means (chaining) to get locations of features along the channel.

**Traverse station method for line features**

Another way of capturing line information is the traverse station method (sometimes known as a point-to-point line feature). This method is analogous to a conventional, compass and chain style traverse. Traverse stations are set along the stream centreline as static point features. The line is created at the mapping stage by connecting the stations. Stations must be set at all significant deflections or bends in the stream. It is also important that there be a maximum distance between points, even though the stream may seem straight.

![Figure 5.13  An example of a traverse station method for line features](image)

**Field Specifications for the Traverse Station Method**
For line (and area) features surveyed in traverse station mode, the maximum distance between stations is 15 metres.

The dynamic traverse method is usually used instead of the traverse station method of surveying line features. The main reason is that the dynamic line method is usually more accurate and reliable than the traverse station method. Under forest canopy, point features tend to be less accurate than line features, contrary to popular belief (this phenomenon is explained further in Appendix C). If any point, especially a deflection station is in error, the line adjacent to the station is also in error – with line features, there are usually many more position fixes adjacent to the errors and the fixes which are in error can be easily identified and rejected.

Another disadvantage of the traverse station method is that the resulting line has no attributes. In addition to stations at deflections and every 15 metres, points must be taken whenever attributes change along the stream (called a segment break). Later the attributes for these points must be transferred to the line feature generated at the mapping stage – a procedure that must be carefully and methodically done to minimize errors. For line features, line segments are much easier to manage both in the field and later during the mapping stage.

The traverse station method has some advantages, however. There are many situations where it is very difficult or impossible to actually walk down the stream centreline – examples include freshet conditions, deep water, and extensive debris in the stream. Using the traverse station method, the field operator can walk along the bank (or along whatever path is best) and venture into the stream only at stations and segment breaks. If the field operator holds the antenna on a pole (versus mounted on a backpack), he or she can just put the antenna over the stream centreline and not have to walk entirely into the stream at stations. Variable station offsets (as described below) make this method even more flexible in difficult walking conditions.

There are also certain man-made features such as drainage ditches which are intentionally straight and usually homogeneous (i.e. the attributes do not change over long distances). In these situations, it is probably best to define the feature by static points at the beginning and end of the feature, even if it is more than 15 metres long. In these cases, though, it is very important to make some form of sketch or field notes indicating how the feature is to be created in the office.
Variable Offset Traverse

A variable offset traverse simply combines the traverse station method with point offsets. It is presented here as a method because it may be the most efficient method for very difficult stream conditions, more than the traverse station method. If it is difficult or impossible to walk the centreline of the stream (the preferred method), it may also be just as difficult to walk into the centre of the stream to establish traverse stations or segment breaks. Using this method, you can remain on the bank and get offsets to the stream centreline from the traverse stations.

![Diagram of variable offset traverse](image)

Figure 5.14 An example of a variable offset traverse.

A variable offset traverse would follow the same field specifications as the traverse station method, and for point offsets.

Supplementary (Fill-in) Surveys

There are times and locations where it may be very difficult or impossible to productively survey a stream using GPS methods. This is due to a combination of tree cover, local terrain (e.g. steep stream banks), and time of day (poor satellite geometry). Sometimes with careful planning, these difficult sections can be avoided, but often it is more productive to do a fill-in survey using conventional methods (e.g. compass and chain).
Field Specifications for Supplementary Surveys

Supplementary traverses (using compass and chain) must begin (Point of Commencement) and end (Point of Termination) on static GPS point features or on survey control monuments of 1 metre or better accuracy.

Directions for supplementary traverses must be accurate to 2 degrees and distances accurate to 1 metre. If the slope is greater than 10 percent, slope measurements accurate to 5 percent or 2.5 degrees must be made. The maximum length of an individual traverse leg is 50 metres. There is no limit on the total length of a supplementary traverse.

All supplementary traverses must begin and end at known locations. Usually, these locations would be static points obtained with the GPS receiver. For example, if satellite coverage is poor in an area, an operator may find an open area or else go back up the stream a short distance to the last area of good coverage to establish a point. At times of poor satellite coverage (usually short periods), it may be necessary to mark the start point for a GPS position later when coverage is better.
From the GPS start point or Point of Commencement (PoC), traverse stations and section breaks are established using conventional means, until the GPS coverage is adequate once more. The same guidelines as for the traverse station method should be followed. Since GPS is usually more productive than conventional traverses and much more accurate over distances, it is preferable to use GPS as much as possible, and only use supplementary conventional traverses where necessary.

Conventional traverses are closed during the mapping stage. To close a traverse means that the calculated end point or Point of Termination (PoT) must be close to the surveyed end point from GPS or previous surveys. Small errors in the field, especially errors in bearings, will accumulate throughout the traverse but they can be adjusted or spread out between the two known GPS positions.

The conventional survey notes must clearly identify the PoC and PoT, and the static points in the GPS file they correspond to. It is a good practice to mark these points in the field so that the traverse can be re-done if it does not close. If the points are not marked, a GPS receiver will be required to re-do the section, a needless expense.

Bearings must be referred to true North and accurate to 2 degrees. Most sighting compasses (i.e. those with a folding mirror or other sighting device) will achieve this precision. Most laser traverse instruments will also provide the required precision.

All magnetic compasses (including digital compasses) refer to magnetic North rather than true North. The difference between the two is known as magnetic declination, and it must be accounted for (in British Columbia, this difference varies from about 17° to about 27°). On most compasses, declination can be set so that field measurements refer to true North. On others, the correction must be made in the office later.

Magnetic declination is usually printed in the margin of maps and charts (including TRIM maps). Since the location of the North magnetic pole varies over time, the time differences from the published date must also be accounted for. Users can also obtain magnetic declination for a location and year on-line from Natural Resources Canada’s web site: http://www.geolab.nrcan.gc.ca/geomag/e_cgrf.html

Magnetic declination is only known to one or two degrees over land – although some manufacturers of digital compasses claim accuracy of better than a degree, this is relative to the magnetic pole, not the geographic North Pole.
Another factor to be considered is local attraction, where large bodies of metal next to the observer can cause large errors (often more than 5\(^\circ\)). This is especially a problem in urban and suburban streams where hydro lines, water pipes, and other man-made objects can cause problems. To minimize the chance of local attraction causing errors in co-ordinates, bearings can be read both ways, that is, reading compass bearing at both ends of a measured line. If the bearings do not agree (they should be 180\(^\circ\) different), there is local attraction at one or the other end of the line. Which end the error is at becomes obvious when looking at bearings on the previous and next lines.

Distances must be accurate to one metre. Tools capable of this accuracy include fibreglass and steel tapes (chain), laser and sonic measuring devices, and even thread chain over short distances (less than 20m). All taped distances must be tight-chained, that is, the chain must be clear of all obstacles between the two traverse stations. The best way to tight-chain is for both users to pull on the chain so that it is suspended between the stations and off the ground.

If there is a significant slope (over 10\(^\circ\) or 6\(^\circ\)) to the line being measured, a slope measurement must also be recorded. Otherwise, the measured slope distance will be longer than the horizontal (map) distance. This factor can be quite significant with steep lines and can easily cause more than a metre error in the distance.

![Figure 5.16 An example of distance taping and slope measurements](image)

**Summary of Line Feature Methods**

Since streams are inherently line features, probably the most important location data in a stream survey are line features. To complicate matters, there are many ways to capture linear data using GPS equipment, and
because of the physical difficulty of mapping streams, any or all of these methods may be used in a single project.

The above sections describe the various methods in detail. They are summarised below:

- The dynamic line feature, walking down (or up) stream centreline, is the preferred method which is usually the most accurate and productive. By suspending data logging, operators can get around minor obstacles such as logs or deeper sections.
- The traverse station method is not as accurate and is usually slower than the dynamic line method, but is quite useful in difficult walking conditions, or at times of poor satellite coverage.
- A variable offset traverse can be used when the stream is deep or in freshet and the centreline is impossible to walk.
- Where poor satellite coverage dictates, supplementary surveys can be used to fill-in gaps in the coverage (e.g. in steep draws).

5.6.3 Practical Receiver Operations

Most GPS receivers, certainly all receivers acceptable for stream mapping under these stream-mapping procedures, allow some user configuration. Some of the configuration options affect the way data is collected, and other options affect the quality of the collected data. Below are the receiver configuration options affecting data quality which are outlined in the Stream Mapping Specifications.

Field Specifications for Receiver Configuration

All position fixes must use at least 4 satellites. No height constraints can be applied.

The minimum elevation angle to satellites is 15 degrees above the horizon.

The maximum Dilution of Precision (DoP) is:

\[
\begin{align*}
\text{HDOP} & := 5 \text{ (preferred in most cases)} \\
\text{PDOP} & := 8
\end{align*}
\]
GDOP <10
VDOP <5 (only if elevations are required)

**Minimum Number of Satellites**

Most receivers will allow some setting for the minimum number of satellites. Simultaneous observations from a minimum of four satellites are required for a GPS receiver to compute its position in three dimensions (plus the error in the receiver clock, which is also required). Some receivers have a mode (sometimes known as a “2-D” mode) where they assume an elevation and only compute the horizontal position. Any such elevation fixing or constraint can cause large errors in the horizontal position and are not acceptable for stream mapping.

**Minimum Elevation Angle**

The elevation angle (angle above the horizon) to the satellites used affects the accuracy of the measurement. Signals from low-angle satellites will usually be less accurate than those from higher angles. This is because the signal will travel through much more of the atmosphere and be affected by various factors such as electrical interference or signal delay. Low angle signals are also weaker because of reflection losses as the signal hits different layers of the atmosphere. The 15 degree figure is chosen as a compromise between signal quality and Dilution of Precision effects (see below), also accounting for separation between the reference station and the field receiver.

**Dilution of Precision (DOP) Threshold**

The Dilution of Precision (DOP) is a measure of how the constellation geometry affects the accuracy of the computed position. A single GPS position computation requires combined measurements to four or more satellites simultaneously. Where the satellites are in relation to each other and to the user’s antenna, is called the constellation geometry. The DoP is a single number which acts as a multiplier – the higher the DoP, the lower the precision of the computed position. Factors which influence the DoP include forest canopy, terrain obstructions, buildings, and daily variations in the satellite orbits.

GPS is inherently a four-dimensional system (three dimensions plus time), and the Dilution of Precision can be calculated in any combination of these dimensions. The most commonly used DoP is the PDOP, or
Position DoP (three dimensions). However, most stream surveys are concerned with the horizontal dimensions only, so the HDOP is a more relevant figure. Usually when the three-dimensional precision is poor (i.e. the PDOP is high), it is because the vertical precision is poor. That is, the HDOP may well be within limits, but the VDOP is too high, and therefore the PDOP is too high.

Most receivers can be configured so that they issue a warning and/or stop collecting data if the DoP gets above certain values. However, most of these filters apply the three-dimensional DoP (PDOP), or even the four-dimensional GDOP. Of course, high VDOP often is the reason for a high PDOP or high GDOP. There will often be times when the PDOP is over 8, yet the HDOP is under 5.

Although positions with a PDOP above 8 are acceptable, positions with an HDOP above 5 are not. That is because it is the two dimensional (horizontal) position which is important for stream surveys. Although such information as stream gradient or bank slope is often important in a stream survey, GPS receivers are seldom accurate enough in the vertical dimension to sense this information, so clinometers are still required.

### 5.6.4 Field Work Under Forest Cover

The combined effects of forest cover and terrain will degrade the performance of all GPS receivers. The GPS signals are affected by the surrounding trees and earth and that affects both accuracy (how close the lines and points are to their true location) and productivity (how much of the time the receiver is tracking enough satellites).

In certain locations, at certain times of the day, it may become very difficult or even impossible to do GPS work. Fortunately, with practical planning, proper equipment, and careful field methods, GPS methods can be used in almost all conditions, even the most difficult conditions of Coastal BC.

In order to productively use GPS under forest canopy, field operators must use careful planning and field methods described below. It is recommended that field operators periodically review the corrected data with mapping/GIS technicians. This will help both field and office people to understand the difficulties and types of errors associated with working under forest canopy.
**Effects of Forest Canopy and Terrain**

The main effect of forest canopy is signal obstruction. Signals are either completely blocked (for example by tree trunks or steep stream banks), or they are so weakened by passing through foliage that the receiver cannot use them anyway. This means that fewer satellites are available to the receiver. The Dilution of Precision increases, with a corresponding loss of accuracy.

In marginal conditions, the DoPs are beyond the specified limits, or four satellites are not available for position computation. This means that the field operator must wait for more satellite signals (or a better satellite geometry) and therefore production is down. In situations of extreme signal obstruction, GPS surveying becomes impossible at certain times of the day.

Signal attenuation (that is, the signals are weakened as the travel through the foliage) can cause a degradation of accuracy as well. Last, signal reflection (known as multipath) can cause large errors, especially for static point features.

Recent testing has shown that high volume, mature stands (rather than more dense, immature stands) cause more problems, especially with regard to productivity. Wet foliage (during or shortly after a rainstorm) causes much more signal attenuation, so much that the signals do not penetrate to the ground where they would if the foliage were dry.

**Mission Planning for Marginal Conditions**

Most GPS receivers provide mission-planning software, which can predict how many satellites will be available for a particular location, and what the DOPs will be. When field conditions are open, mission planning is seldom required, as there are almost always enough satellites with adequate geometry (low DOPs) to meet the stream mapping specifications. However, in the marginal conditions of heavy forest cover and steep terrain this is not the case.

There are certain times of the day where the GPS coverage is marginal (few satellites), and other times where it is excellent (many satellites). Forest cover or terrain blockage can turn the times of marginal coverage into times of no coverage, and times of excellent coverage into times of marginal coverage.

It is of course impossible to reliably duplicate real-world field conditions with planning software, regardless of impressive options such as
integrated terrain models (these are usually more useful for sales and demonstrations than in real life). However, a reasonable approximation of the conditions can be done easily by assuming the lower angle satellites will not be available. Most packages have a provision for applying a minimum elevation angle. Others allow the user to choose specific satellites for exclusion in the DOP calculations.

Experience has shown that assuming a minimum elevation or 25 for coastal conditions (heavy forest cover), or 20 for interior forest conditions provides a realistic, if somewhat pessimistic, approximation of the conditions in the field. This of course will vary with many factors, and the numbers can be fine-tuned for local conditions by noting the difficult times in the field, and then attempting to re-create them with the mission planning software after the fact to arrive at a reasonable value.

Field operators should be aware of the times of the day when coverage is best. The most difficult sections should be surveyed during the times of best satellite coverage. If there are definite times of poor coverage, this is the time non-GPS tasks could be planned, or more open areas could be surveyed. Naturally, there will always be times when it is not feasible (for logistical or other reasons) to perform other tasks, and field operators will have to accept that it may take much more time to survey some sections.

**Receiver Configuration**

Although the configuration options described in section 5.6.3. should not be changed (as they are part of the specifications), there are often certain receiver settings which may provide better performance will little or no degradation in accuracy.

A few receivers have configuration settings, which will ensure maximum productivity, although accuracy may be degraded somewhat. Depending on the receiver, it may be known as maximum tracking, SNR mask, or other names. The idea is that the receiver may accept weaker signals (such as signals passing through foliage), which may be less accurate than strong signals (not passing through foliage). Receivers without this option will usually accept any signal at all – that is, there is no signal strength filter applied.

The best differential GPS receivers are capable of accuracy better than a metre – in ideal conditions, using the manufacturer’s default configuration. With these receivers, however, the default configuration (e.g. maximum accuracy or SNR mask 6) usually means that the
equipment works poorly in forest cover – if at all. These manufacturers usually suggest that relaxing the default settings will allow data collection under forest canopy, although accuracy of better than a metre is not guaranteed by the manufacturer.

The stream mapping specifications specify five-metre accuracy, at the 95% confidence level. Although most mapping grade GPS receivers can meet this requirement in ideal conditions, there are very few receivers which can meet the requirement under forest canopy. The list of currently acceptable receivers is available from the Sensitive Habitat Inventory and Mapping Specifications committee.

Receivers, which have been accepted, have been tested rigorously and extensively under coastal forest canopy, and will meet these standards as long as the settings in 3.4 are adhered to. Even with such settings as “maximum coverage” or “SNR mask 0”, they can meet the accuracy requirements. Although they will not be accurate to one metre under forest canopy, they are accurate to five metres or better, 95% of the time.

Accepting weaker signals means that more satellites are available to the receiver, and that the Dilution of Precision is lower (than for the manufacturer’s default). Because the DOP is directly related to the position accuracy, more satellites and a lower DOP will usually mean better accuracy under forest canopy.

When working under forest canopy, it is usually preferable to configure the receiver to accept weaker satellite signals. Accepting weaker signals (for example setting the SNR mask lower than the manufacturer’s default) does not degrade the accuracy under forest canopy beyond 5 metres, 95% of the time. However, accepting weaker signals will ensure considerably better production under forest canopy and will make GPS surveying possible in most situations.

**General Field Methods**

When working in difficult conditions, field operators must pay careful attention to the receiver tracking. Most receivers will provide some audible feedback to the operator, with different sounds signifying different events. Most receivers will play a sound (a beep) when there is a successful position fix – when the receiver is silent, no data is being collected. Others are silent when data is being successfully captured, and sound a warning when no data is captured. Field operators may prefer one or the other, but it is essential that the field operator know when data is being successfully collected.
Static Point Features

Under heavy forest canopy, static point features can experience quite a bit of error. This is because the signals from the satellites are affected by the tree trunks, branches, and foliage. Static points are particularly susceptible to large errors because the relationship (geometry) between the satellites being used, the GPS antenna, and the trees and other objects affecting the signal does not change very fast. On line features, that relationship is constantly changing as the antenna moves and the errors are much easier to deal with.

For point features, the best way to increase accuracy is to stay longer. Over time, the errors will average out and the resulting point will be more accurate. However, recent testing indicates that point occupation times must be 5 minutes or more for the errors to effectively average out.

Another way to increase point accuracy may be to change certain receiver settings. If the receiver allows users to select a Dilution of Precision (DOP) cut-off value, this might be lowered. Some receivers have other settings such as maximum accuracy or Signal-Noise Ratio (SNR) threshold.

Naturally, however, there is a trade-off between accuracy and productivity. Any of the above measures will certainly decrease the productivity, to the point where it is not possible to work around the trees. Obviously, taking longer at points is going to mean that the survey takes longer. Changing receiver settings often means that the receiver does not get signals at all under forest canopy.

One method, which may work, for increasing point accuracy is to move the antenna around during the occupation. This seems counter-intuitive since the idea of a static occupation is that the antenna is not moving. Some movement may help to change that geometry between the satellites, antenna, and trees and foliage. Very limited testing has been inconclusive and more testing is planned. Until then, it cannot hurt to move the antenna around a bit within reason and considering the accuracy specification – 1 metre or so should not cause problems, and it may help. Regardless, in difficult conditions, it is often necessary to move the antenna somewhat as signals are lost and re-acquired.

There are some points for which accuracy is very important. Usually these will be points which have no associated line (i.e. are not points along a dynamic line survey), and that have some special significance. For example, legal survey monuments (property corners) or Points of Commencement for a supplementary traverse. In these cases, the
occupation time should be increased, or perhaps a more open area found and a point offset performed.

*Dynamic Line Features*

Line features tend to show random errors in the individual position fixes making up the line. Because of this, it is essential to collect much more data than would be strictly necessary to define the line’s location and shape. When working in marginal conditions, it is very important to collect as many positions as possible. In difficult conditions, field operators should log data as fast as possible (usually one second), even if that means that fixes are less than a metre apart.

After differential correction, a mapping/GIS operator will generate a smooth line (interpreted line) using the position fixes as a guide. This line is usually drawn over top of the GPS data, rather than selectively deleting position fixes deemed to be in error (a very time-consuming process). The fundamental rule for creating this interpreted line is that more data is better, as it provides the operator with more information to base decisions on. More data will ensure a more reliable and accurate final line, and it does not require any more time at the mapping stage.

The biggest problem with surveying dynamic lines in difficult conditions is that gaps in satellite coverage mean gaps in the line. Field operators must pay very special attention to these gaps and ensure that they do not become too large. Sometimes it is necessary to walk back and forth over a certain section to ensure there are enough position fixes that the line can be defined at the mapping stage. Moving the antenna across the line (left and right of the stream centreline) often helps. Since the receiver has 1 metre accuracy at the best of times, a metre left or right of the centreline will not degrade the accuracy of the final product at all.

For dynamic line features, it is a good idea for the field operator to visualize the map being made. Each successful position fix can be thought of as a dot, and field operators can keep a virtual map in their minds as they are surveying in difficult locations. Field operators should think about the gaps in the line, and should ensure that there are enough fixes to define bends and meanders in the stream.
5.7 Planning and GPS Processing

GPS receivers almost always come with software, which performs several GPS-specific tasks. Usually, these tasks include: pre-mission planning, data and project management, receiver download, reference station search and download, differential correction, and exporting to GIS or mapping software (such as ESRI’s ArcView).

In some situations, it is possible to obtain real-time corrections, that is, observations are corrected in the field and the positions stored in the GPS receiver are corrected before downloading to the computer. Real-time corrections have certain advantages and limitations and there are many factors to be considered before relying on real-time surveys.

This section considers some of the functions typical of planning and processing of GPS products. Where appropriate, practical advice is included.

5.7.1 Pre-Mission Planning

Mission planning shows the optimum times to do field work and shows when it will not be productive to use GPS (especially under forest canopy). This is fairly simple to compute from geometry (knowing the user’s position, the satellite locations, and the proposed time).

However, users must remember that mission planning is only a theoretical tool and does not predict real-world survey conditions. Forest cover, local terrain, or satellite outages all mean that coverage predicted by mission planning software is optimistic at best.

Mission planning software requires three inputs: the user’s location, the intended date and time of the survey, and a current almanac. Interpreting the results requires common sense and experience.

The user’s location can easily be obtained from topographic maps, or even road maps. The user location only needs to be accurate to a few hundred kilometres (about 2 degrees of latitude or longitude in BC). For surveys on the ground, the user’s elevation is not important.
It is important that the local time offset from UTC (the time zone) is accounted for in the mission planning. Most mission planning programs assume that planning is being done on UTC (six to eight hours ahead of local BC time). There will be a provision in the software to allow users to specify a local time zone.

GPS satellites work on a sidereal day, rather than a solar day. Consequently, mission planning times are based on a sidereal day. Although the time will be correct within a few minutes for the specific day, the times of concern (high DoP, few satellites) will advance by four minutes per day, or approximately 30 minutes per week. If a mission plan is done for a Wednesday, times will be 8 minutes earlier on the Monday and 8 minutes later on the Friday. After one week (a 28 minute difference), it is probably wise to generate a new mission plan.

The operators of the GPS satellites often take satellites off-line for maintenance or to change their orbits. Periodically, satellites will be decommissioned and new ones will be launched and made available. Maintenance usually affects one or two satellites per week, so it is important that users consider scheduled maintenance in the mission planning process.

Users should ensure that they have a current almanac, which describes the orbits and status of the satellites. For future planning (for example if a satellite is scheduled for maintenance), users should also know about forecast outages. For current almanacs and for information about the status of GPS satellites, the official website for GPS information should be consulted: \( \text{http://www.navcen.uscg.gov/gps/default.htm} \).

Often manufacturers and/or vendors will make this information available on their own web sites (including perhaps almanac files in proprietary format).

When working under heavy forest cover or in steep terrain, mission planning becomes more important than ever. Section 3.6.4. provides some practical advice for mission planning for work under difficult conditions.

5.7.2 GPS Reference Stations

GPS surveys done for mapping purposes use a technique called differential GPS. Observations made at a known reference station are used to correct some errors, which will be noticed at both stations.
Without differential correction, the expected accuracy of GPS positions is about 20 metres.

Normally, GPS mapping surveys are done as post-processed surveys. During the survey, GPS data is stored on the field receiver, and on a reference receiver. After the survey is done, data from both receivers is downloaded to a computer and the positions are differentially corrected after the survey.

Another method of differential correction is real-time (RT) differential GPS. Instead of storing the corrections at the reference station, they are broadcast as soon as possible to users in a local area. If the users have the appropriate equipment, their GPS receivers can correct positions in real-time and display and store corrected positions in the field, rather than waiting until later to get corrected positions.

Post-Processing Reference Data

There are a number of reference stations in or near to British Columbia which provide reference station data for correcting GPS surveys. Typically these stations are available through Internet access (ftp or web-based). Most manufacturers provide some form of automatic Internet search and download in their processing software and in many cases, users are given a choice of reference stations appropriate for stream mapping.

In British Columbia, there are two main providers of post-processing reference data: Terrapro GPS Surveys Ltd., and Geographic Data BC (an agency of the provincial government). Other private companies have reference stations, but do not provide public access to the data.

Both GDBC and Terrapro provide reference data on a subscription (user-pay) basis, usually based on an hourly, monthly, or yearly agreement. For stream mapping purposes, there is no practical difference in the quality of the data so users should make decisions based mostly on convenience or local concerns.

There are also a number of reference stations in British Columbia, operated by the Geological Survey of Canada for which access is free although not always convenient. In the US, government agencies such as the National Geodetic Survey, Coast Guard and the Department of Transportation have established a network of reference stations known as CORS (Continuously Operating Reference Stations). Access to this data is free and there are several stations appropriate for stream surveying in British Columbia.
Figure 5.17  GPS reference stations in and around British Columbia, Canada.

- Geographic Data BC (subscription based):  
  [http://home.gdbc.gov.bc.ca/](http://home.gdbc.gov.bc.ca/)
- Terrapro GPS Surveys Ltd (subscription based):  
  [http://www.terrapro.bc.ca](http://www.terrapro.bc.ca)
- US CORS system:  [http://www.ngs.noaa.gov/CORS](http://www.ngs.noaa.gov/CORS)

**Real-Time GPS Surveying**

In the field, there are often advantages to having real-time corrections available. If operators must find features which are very difficult to identify visually (e.g. buried treasure), then real-time GPS may be the only way to find them. Depending on the receiver, users may be able to review their data in the field as a limited quality control (QC) tool. Some systems allow users to upload spatial data (e.g. orthophotos or existing stream data) and display it as a background to the field data capture – these systems usually require a real-time GPS system.
In the office, the benefits are marginal at best. Having the data corrected in real-time may save some time in the processing stage, but with most modern software, this is only a matter of a few minutes of processing for a full day’s work. Downloading the data from the field receiver and dealing with the errors in the corrected data are the most time-consuming part. One consideration is that in most instances, reference station data is sold for a fee – if real-time data is available, and 100% reliable, using real-time corrections might save money.

Real-time corrections are seldom as accurate as post-corrected GPS, given the same conditions at the reference station. That is because real-time corrections always have some latency built-in – there is a time lag between the reference station observing the corrections and the corrections being applied at the rover. However, this additional error is usually less than one metre, and not really significant for most mapping surveys.

The primary disadvantage of real-time DGPS is the added complexity of the system. Most real-time systems require an extra antenna and radio (these are sometimes integrated into the GPS unit), and the attendant problem of cables, connectors, and batteries.

Productivity will drop markedly if the real-time system is not 100% reliable (that is, whenever users can receive GPS signals, they can also get the correction signal). Real-time corrections are seldom 100% reliable, except over very small areas. If at all possible, users should configure the receiver to store uncorrected GPS data (for later post-processing) whenever real-time data is not available. If a survey is corrected using different reference stations, users should ensure that there are no “jumps” or other systematic errors at the changeovers.

For stream mapping, there is usually no distinct advantage to having real-time GPS corrections. There is seldom a need for navigation accuracy better than 15–20 metres available with autonomous GPS. In fact, the disadvantages of real-time GPS often out-weigh the advantages, especially given that free or inexpensive reference station data is available throughout BC.

Coast Guard DGPS (Coastal Areas)

The Canadian Coast Guard (CCG), along with the US Coast Guard and many other nations, has developed a system of beacons broadcasting real-time GPS corrections free to all users. The system uses a low-frequency signal, which provides coverage up to 50–100 km inland from
the beacon. Forest canopy and terrain blockage affect the signal only marginally, making it ideal for stream surveys in coastal conditions.

The primary disadvantage to the Coast Guard Beacons is the limited range inland. The signal is designed to use seawater as a conductor (like an antenna) and the signal strength drops off quickly inland. Actual coverage will depend on many factors such as weather, terrain, and local radio frequency interference.

The US Department of Defence has established several stations inland (including Spokane, WA) which broadcast using much more power (often 10 times more) than the coastal stations. These stations are part of the Nation–wide DGPS (NDGPS) system and their range is usually close to 200 km.

The location of the Coast Guard (and NDGPS) beacons is shown in figure 3.1. More information is available at:

- Canadian Coast Guard: [Hyperlink]
- US DGPS: [Hyperlink]

**Satellite–based DGPS (Inland)**

Away from the coastal areas or the US border areas, satellite–based services are usually the only option for real–time correction signals. These use geo–stationary communications satellites and broadcast on a frequency very similar to the GPS satellites.

Satellite–based signals are subject to the same blockage and attenuation that affect GPS signals in the forest. Trees, foliage, and local terrain will block the signal. Unlike GPS where there are many satellites available (so that blocking one or two signals will not affect productivity), these services are usually broadcast from a single satellite for an area, and the signal will be blocked much more often.

For flat areas, even heavily forested areas, periodic signal blockage is not always a concern. Since selective availability was removed (May 2000), users can safely configure their equipment to accept a correction age of 120 seconds. As long as the signal is re–acquired during that period, no outages are apparent to the user.

Local terrain conditions, however, can adversely affect satellite–based DGPS. The satellites are typically located to the Southeast of the user, at an angle of 20–30 degrees (depending on the latitude). Especially for
stream surveying, local terrain (e.g. a steep stream bank to the South) can mean significant outages.

There are many providers of satellite–based DGPS services, usually on a subscription basis. One recent development is the Wide Area Augmentation System (WAAS), which broadcasts free correction signals using the same frequency and coding as the GPS satellites themselves. WAAS–capable receivers are becoming common in 2001.

5.7.3 GPS Data Processing

After the field survey is complete, the data must be further processed to make it ready for GIS and/or mapping use. Data management and archiving becomes extremely important given the amount of data collected during a GPS survey.

Data Management

Good data management will ensure an efficient project. Data loss is a threat on complex projects through duplicate file names, lost files, harddrive failure or backup. File, job, and project naming conventions must be created for projects and followed rigorously. Such conventions must be systematic and unique so others can readily find files and documents related to a project.

In the field, data is usually managed through file names or job names. Often, a receiver will suggest names based on such things as receiver serial number, date and time, or sequence. While these default–naming schemes are usually systematic and unique, project managers may prefer a different naming convention.

Naming conventions might follow some pattern using one or more of the following: project designation; stream name; reach identifier; tributary identifier; date; time; field operator's name or initials; sequential numbers, etc. If the field receiver does not allow long file or job names (or comments attached to them), names can be changed after downloading, before importing into a project.

During the data processing stage, files downloaded by the receiver are supplemented many times over by intermediate files, reference station data, corrected files, export mapping data and final mapping files. It is absolutely essential that operators know where all of these files reside, and when certain files are no longer necessary.
Most GPS programs help users manage GPS data using projects which store various computer files in predictable locations. Like field file naming, project folders suggested by the GPS manufacturer may not be the preferred convention. The locations (folders) for data can usually be changed to suit local project conventions. For example, many organisations may wish to store all reference station data in a certain directory, or all GIS export files for a specific day or stream reach in one folder.

It is essential to develop a simple, practical, and complete convention for naming of files and projects, and for locations of data files. Whatever naming convention is adopted for a project, it must be used consistently.

**Differential Correction**

In order to meet the accuracy requirement of the SHIM Stream Mapping Specifications (5m at 95% confidence for line features), differential correction is always required. This applies even though Selective Availability (SA – the deliberate degradation of GPS accuracy) has been discontinued.

Some people claim that autonomous GPS can be accurate to 5 metres, but such claims are invariably based on very limited experience under very ideal conditions. Extensive testing since SA was discontinued has shown autonomous GPS (i.e. not differentially corrected) to be accurate to about 10 metres, 95% of the time. Effects of forest canopy add another 2–10 metres (depending on the receiver) to this figure.

A problem which has become apparent since the removal of SA is that often, uncorrected GPS data looks good. That is, the data looks fairly smooth and it may seem that differential correction is not required. However, uncorrected GPS data is usually subject to a systematic error. The error does not change much over short time periods (a few hours) but it may be ten metres out or more. Even though the data may look good, and even be repeatable over a short time, it is likely to be quite a bit in error. Without differential correction, there will always be an uncertainty in the position.

Fortunately, differential correction is usually a very simple procedure for users, and takes very little time. Downloading receivers usually takes much more time than differential correction. Usually the manufacturer’s default settings for correction are appropriate and further operator intervention is not required. If anything, the settings must be changed
once and then left for most circumstances. If all positions are corrected in real-time (see 5.7.2.), further differential correction is not required

**Project Deliverables and Archives**

Depending on the structure of a stream-mapping project, some files should be included as deliverables (for example to a stakeholder agency), and some could be locally archived for future reference and troubleshooting. The standard deliverables for most GPS projects, outlined in the Appendix C include:

- Uncorrected GPS data (originally downloaded from receiver).
- Reference station files (in RINEX or proprietary format).
- Original corrected data (in proprietary format or GIS format).
- Final edited GIS (map) data with features and attribute.
The SHIM standard deliverables; formats, uses, and additional issues include:

**Raw (Uncorrected) GPS Data**

This is the data file originally downloaded from the receiver or datalogger. There must be no editing done to this file, as it is considered the equivalent of field notes for a conventional survey. If there is ever a dispute over some aspect of the survey, these are considered an unaltered record of the fieldwork.

For at least one receiver (Trimble), it is possible to edit uncorrected GPS files to some extent (e.g. removing a segment of a traverse) using the provided software. If the case of Trimble receivers, there is actually a downloaded file which is unalterable (not the SSF file) and this file should
be used as the original file if available. For other receivers it is virtually impossible for even experienced users to actually edit the raw GPS data

Reference Station Files

Unless the survey was done entirely in real-time (therefore the above uncorrected data is actually corrected), data from a reference station is required to differentially correct the survey (see 5.7.3.) Reference station data is usually downloaded in one-hour segments, so there may be many different files associated with a GPS survey (which often is done over the course of many different days). Typical file sizes are 0.2Mb per hour compressed. After interpolation to one second and merging, a day’s reference file can easily reach 20Mb.

Although ideally, it is preferable that reference station files are submitted along with the standard project deliverables, this is not always practical. The sheer size of reference files makes them very difficult to handle for both the organisation performing the survey and contractor and to any agency the data is delivered to. It may be preferable to archive the files locally (for example on a CD backup), and the reference files would only be accessed if there were problems with some of the data.

Reference station files (either as a deliverable or if they are archived) are acceptable in either a manufacturer’s proprietary format or in the text-based, independent RINEX format. Whatever format was originally downloaded is preferable.

Original Corrected Data

The original corrected data are the unedited positions after differential correction. Normally in British Columbia, GPS mapping surveys are post-processed – that is the files are corrected using reference station data after the survey. However, if the survey was corrected in real-time (for example using the Coast Guard Beacon signals available near the coast), the file downloaded from the receiver may still have some uncorrected positions in it. All uncorrected positions should be filtered from the file or else subsequently corrected using post-processing.

The positions in this file will have some residual errors in them. With state-of-the-art equipment, in very good conditions (flat and open) these may be quite small and the corrected file becomes the final map file. However, in most stream-mapping surveys in the real world, these residual errors can range from a few metres (with the best equipment) to tens of metres. These errors must be properly handled to make the final
map product. Quality assurance (QA) procedures will require these files as well as the final GIS/map files to assess the extent of the errors, and how well they were handled. The original corrected GPS file is the most important piece of information for any QA purposes. The original corrected data will show the general level of accuracy of the data.

This data is could be in the manufacturer's proprietary format or in a GIS format such as ArcView shapefiles. Regardless of the format, it is absolutely essential that this is the original corrected data, and that no editing has been done after differential correction.

*Final GIS (Map) Data*

This data (for ArcView a series of shapefiles and associated files) has the geographic features (points, lines, areas) derived from the corrected GPS data. It will also contain the attributes captured during the survey, transferred if necessary to edited or derived features. Any important topological relationships (e.g. network files) should be included with this data.

Then final GIS data should follow certain cartographic, topological, and naming conventions. Although such conventions are beyond the scope of GPS stream mapping specifications, they are very important to a project. Project managers should ensure that all stakeholders have input into the local conventions if there is not a standard convention available. A summary of these conventions should be delivered and archived along with the GIS data.

**5.8 Mapping And Data Quality**

The most important phase of a GPS surveying project is the post filed mapping and data interpretation stage. This is where the residual errors (i.e. the errors left after differential correction) in the positions are assessed and further corrected. Although the best GPS receivers can give consistent metre–level accuracy or better in ideal conditions, accuracy from even the best receiver is significantly degraded in more difficult conditions, such as around trees and buildings.
Because less than ideal conditions are the normal during most stream surveys, it is important to understand the nature of the errors and how best to correct them.


5.8.1 Using GPS Data in Mapping and GIS Software

Most of the data interpretation stage is done using GIS or mapping software such as ArcView or MicroStation. Although most GPS software does have some editing and map-making capabilities, these tools are usually extremely limited. Recognising this fact, all GPS manufacturers provide links to most popular GIS and mapping programs. In fact, some manufacturers actually store their data in popular GIS formats.

Transferring GPS Data to GIS Formats

It is important that as much information as possible is transferred to the GIS or mapping program being used. Ideally, the following positional and attribute information should be transferred from the GPS software to the GIS software being used for editing and creating the final databases and maps:

- Features generated by the GPS receiver or GPS software, and associated attributes.
- Individual position fixes for all features.
- Supplementary quality information.

The minimum information, which must be transferred, is the location of the features and the attributes. All GPS software intended for GIS data capture will export this data. Occasionally however, the method of handling the attribute information (either by the GPS software or by the GIS/mapping program) is not ideal. Sometimes GIS/mapping software, particularly the lower-end CAD (drawing) programs cannot accept the attributes of the features.
It is quite valuable to have the individual GPS position fixes as well as the features derived from those fixes. Figure 5.19 shows features (a point and a line) along with individual fixes. By including the fixes, trends, deficiencies, and the general level of data quality is much more apparent.

There may be some supplementary quality information available from the GPS software (this may require specific settings or even a third-party program). Examples might be the standard deviation for averaged point features or DoP figures for individual fixes. Some manufacturers include an “omnibus” quality estimator, usually based on a proprietary combination of other quality information. Unfortunately, statistical quality information is often of limited use, especially for surveys under forest canopy. It is up to users to decide whether any supplementary quality information is reliable and practical.

**Interpreted Features**

GPS position fixes, even after differential correction, will have some residual error. This error may be on the order of a metre with the best equipment in open flat conditions, to ten metres or more under heavy canopy in steep terrain typical of stream surveys. If these errors are small, the points, lines, and areas created by the GPS software after correction may adequately represent the true feature. However, most GPS surveys done under forest canopy require some further editing or interpreting of the features created by the GPS software.

![Interpreted Features Diagram](image_url)

Figure 5.19  Examples of errors in collected GPS features.

Figure 5.19 presents some of the typical errors in point and line features. There are several methods for dealing with these errors:

- Selectively deleting individual fixes deemed to be in error and re-creating the features.
- Using statistical methods in software to reject “outliers” in points and to automatically smooth lines.
- Visually creating or moving features using the corrected GPS positions as a guide.

Of the three, the third is by far the most common method, and this interpretation is usually done using GIS or mapping software. For points, if the point is obviously in error, it is moved to its most likely position (e.g. on the traverse line). A new smoothed line is drawn using the old GPS-derived line as a guide, and any attributes are transferred to the new line (Fig. 5.20). This method relies on the mapping operator having an understanding of the nature of the errors in GPS positions, and making decisions based on experience and common sense. Although it seems like an approximate method, if carefully done, this method is the most efficient and – especially for line features – gives results closest to the true locations.

**Figure 5.20** An example of interpreted final line and point features

**Data Management for Interpreted Features**

The original corrected GPS data should never be edited. It is best to export this from the GPS software immediately after correction – if any edits are made using the GPS software, they must be made to a separate file. Once the original corrected GPS is in the GIS format, any edits or changes should be done to a copy of the original data. This is especially true if the original corrected data cannot be easily re-generated. For example, if the GPS software is only rented and must be returned.

For point features, points are typically moved in a copy of the original corrected data. For line features, a new interpreted line is usually generated using the original corrected data as a guide (Fig. 5.20). If new
features are generated for any feature (rather than just moved), the attributes for the original feature must be copied or transferred to the new feature. If the original feature had segments (e.g. a stream reach where attributes will change for many segments of the reach), then the interpreted line must have segments and the attributes must be correctly transferred between segments.

5.8.2 Quality Control in GPS Position Data

The following sections are intended to help stream mappers understand the nature of errors in GPS positions and how to assess GPS data quality.

Concepts in GPS Data Quality

Quality Control (QC) of conventional survey data has typically been based on the concept of relative closure. Comparing the computed location of the end of the traverse (Point of Termination) with the expected values (either the same as the Point of Commencement, or some known coordinates) provides a closure error. The relative error is the ratio of the closure error and the total distance traversed (e.g. 1m/100m). Since errors in a conventional traverse usually accumulate throughout the traverse, a simple mathematical relationship exists between the likely error at any point of the traverse and the measured error at the end of the traverse.

Errors in GPS positions, however, do not accumulate throughout a GPS traverse. They are quite independent of each other – in time and in space. The error noticed at one place in a GPS survey (for example by a tie to a known location or re-surveying part of a traverse) is a very poor indication of the error, which would be noticed at any other location. Nor would the error noticed at one place at one time be the same as the error noticed at a different time at the same location. This makes QC of GPS data seem like a daunting affair, short of re-surveying everything.

However, there is one property of GPS surveys, which can be exploited for QC and Quality Assurance (QA): GPS surveys typically contain far more than the minimum amount of information to define the feature being surveyed – this is known as redundancy. Usually more than the minimum of four satellites are used in computing individual position fixes. Point features are usually averaged from many individual position fixes, and line and area features usually have far more points than are actually required to define the line or the area boundary.
This redundant information can be used for statistical analysis (for example, standard deviation, observation residuals, proprietary quality indicators) to give an indication of quality. However, statistics can be very misleading and, with the level of GPS used in these stream-mapping specifications, are often not reliable indicators of actual accuracy. Further, statistical analysis can be very complex and difficult for personnel not experienced in using GPS and geodesy to properly interpret.

A practical method of QC is visual – if the data looks good, it probably is. Personnel with a fundamental understanding of GPS survey methods and the nature of errors in under-canopy GPS surveys can easily perform QC or QA on most data.
Figure 5.21 Visual quality analysis for line features (original data)

Figure 5.21 illustrates an acceptable analysis of information. In many cases visual quality analysis will help easily distinguish acceptable, marginal or unacceptable interpreted features according to SHIM mapping specifications. This common-sense analysis can be a basis for assessing the quality of GPS data for stream mapping.

**Components of Overall GPS Quality**

When assessing the quality of geographic data derived from GPS, there are three components which must be considered: Accuracy, Reliability, and Completeness.

**Accuracy** describes how close the geographic entities (points, lines, areas) derived from the GPS survey are to their true values. Of course, the true position of a feature is probably never known (otherwise, a survey would not be required in the first place).

True accuracy is very difficult to test and is seldom done since it requires a re-survey to a much higher level of accuracy (e.g. using total stations). However, a reasonable test for accuracy is to visually examine the data and assess the overall error.

**Reliability** describes how reliable the derived features are. That is, can their depiction on the map be trusted throughout? There may be deficiencies in the field data collection such as too few position fixes at a point feature or too far between position fixes along part of a line feature. Careful field procedures (supplemented by Quality Control at the processing and mapping stages) are necessary to ensure reliability.
Reliability can be easily tested through simple QA procedures by checking for compliance with certain specifications for stream mapping such as minimum time for static point features and maximum gap along dynamic line features.

Completeness is a management issue, rather than a technical issue. Many stream mapping projects are very complicated and important details may be omitted or incorrectly represented. Although the GPS data may be accurate and reliable, the final map may not properly represent the location on the ground – this is perhaps the most common cause for large area errors since entire sections may be missing or wrong.

For example, a stream system may be several kilometres long, with many reaches, confluences and tributaries. Ephemeral channels and tributaries often must be mapped, and headwaters as well. Often during the course of a stream survey, there will be re-surveys and amendments as crews become more experienced and new attributes become important. The final dataset may come from GPS data captured by several different crews, using different equipment and methods, over quite a few months. Given these complications, it is not uncommon for a segment or tributary to be missed. It is also not uncommon for features to be included mistakenly (for example approximate locations and features for planning from existing, inaccurate information).

It is vital that systematic records of data capture are kept, and that somebody very familiar with the stream network assume overall responsibility that all features are properly mapped in the field and at the mapping stage.

5.8.3 The Nature of Errors in GPS Positions

GPS positions, just like all measurable quantities, cannot be determined exactly – there will always be some error, even if it is very small. The methods used for forestry GPS surveying can yield, using the best equipment and under the most ideal conditions, accuracy of 1 metre or better. However, in typical field conditions (forest cover and steep terrain), errors of 5 metres or more are common even using the best equipment. Using lower-quality equipment, errors of more than 10 metres are not uncommon.

There are three general classes of errors in GPS positions: gross errors, systematic errors, and random errors. There are different ways of dealing
with these different types of errors. It is essential that the errors be recognised for what they are and properly handled.

**Gross Errors**

Gross errors are usually the result of some avoidable mistake and hence are often known as “blunders”. One common blunder is transposing numbers, for example writing 27 when 72 was actually the number observed. With GPS positions, gross errors are usually the result of signal tracking problems with the GPS receiver – these sometimes happen, especially in difficult observing conditions.
Gross errors in GPS positions are usually very easy to identify, as they are usually quite large and of very short duration (a second or two) (Fig. 5.22, 5.23). They usually show up as “zingers” where one position fix is obviously in error compared to the rest of the fixes. Gross errors are usually tens or even of hundreds of metres different from the adjacent fixes (Fig. 5.24).

To help identify gross errors, it is important that redundant measurements are available. With enough information, gross errors become obvious visually and those fixes can be easily ignored or deleted.
during the interpretation stage. Some software packages will attempt to automatically identify and eliminate gross errors. Gross errors in line can often be identified automatically since they imply a ridiculous condition, such as a field operator suddenly moving 50 metres in one second, then moving 50 metres back the next.

Point features do not seem to be as susceptible to gross errors as are dynamic lines. Actually, the effect is more a combination of gross and systematic errors – instead of one or two individual fixes which are out, it is a series of fixes.

Systematic Errors

Systematic errors follow some pattern which affect the measurements or calculations. There is a bias which is usually about the same magnitude (size) and direction or else, follows an obvious trend. Systematic errors in measurements are usually the result of some sort of natural phenomenon, equipment calibration, or observer bias. Systematic errors can also be introduced during the calculation process by ignoring – or incorrectly assuming – certain factors.

A common systematic error is the magnetic declination – the compass needle points towards local Magnetic North, whereas grid or UTM North is the reference for most resource-grade maps (which includes another error, the grid convergence). If these factors are not accounted for, compass observations are many degrees in error. With GPS positions, the main systematic error is due to a phenomenon known as multipath (see section 5.8.4.), which is often exacerbated by receiver or processing software.

If the cause of the systematic error is well–known, the errors can often be modeled, where a mathematical formula is applied to correct the errors – for example, compass declination is based on a model. Observing techniques can also correct for known systematic errors – for example, simple differential correction accounts for most of the common–mode errors in GPS observations (see section 5.7.2.).

The problem with systematic errors is that they can be very difficult to detect if the cause is not known and well understood. With GPS data in difficult conditions (e.g. under forest canopy or around buildings), the position fixes may look right, but be many metres in error. Undetected systematic errors are one of the main causes of poor quality in GPS
surveys.

Figure 5.25  An example of systematic errors in point features (actual data)

Figure 5.25 shows systematic errors for point features, although it is an extreme example. The obvious trend in the error is very typical of systematic error for point features. In this instance, there are a few (8 out of 160) position fixes which are seem to be gross errors, although they have a systematic component (that is, they follow the pattern or trend of the errors).

Figure 5.26  An example of systematic error in line features (actual data)

Figure 5.26 shows an example of systematic errors for a line feature. This is also an extreme example, but it illustrates the difficulty of detecting systematic errors. The GPS position fixes give a smooth appearance, and actually look like very good data. Only when the true location of the feature is known do these systematic errors become obvious. There is no visual or statistical clue that the data has such large errors.

In this case, the only reliable clue to the existence of large systematic errors is the brand of receiver since it is the receiver and software combination which has caused the error (other receivers tested simultaneously did not have the same errors). It should be noted that the receivers most commonly used in stream mapping in BC seldom exhibit such systematic errors in dynamic lines – and then, of very small magnitude (usually much less than 5 metres).

Random Errors

If there are no gross or systematic errors in a data set, random errors are what remain. Random errors are residual noise in the data caused by unavoidable effects including environmental effects and the measurement resolution of the equipment. Truly random errors are easily identified visually as there is no definite pattern to them – that is,
the size and direction of random errors cannot be predicted by what has come before or what comes after.

Usually, random errors are small and are just as likely to be positive as negative (or for line features, just as likely to be off to the right as to the left of the line). Because of this, truly random errors will average out if there is enough redundant data.

Figure 5.27 shows random errors in a point feature, although it is an extreme example. There is no particular pattern to the errors, although a slight NNW trend can be seen. Usually the most prevalent error in point features under forest canopy is systematic, but with enough data, averaging can produce a good estimate for the true location.

Figure 5.27 An example of random errors in point features (actual data)

The best estimate for the true position of a static point with random errors is simply the mean, or average of the point. This is based on a statistical method, which minimises the sum of the squares of the residuals, known as least squares. All GPS software that will handle point features will compute averaged points thus, dealing with random errors in point features is very straightforward.

Some software however, may apply some other processing to the point features. One method is known as outlier testing where any individual position fix which is more than a certain distance from the computed average is rejected, and a new average is computed. Usually that distance is set at two times the standard deviation of the averaged point. Such processing schemes can cause problems since they assume that the errors are truly random when in fact usually the most prevalent error is systematic in point features under forest canopy.
Figure 5.28 shows random errors in a dynamic line feature, also an extreme example. Although the data is very “noisy” there is no particular trend to the errors. Ignoring the obvious gross errors, a line which best fits the position fixes is actually quite close to the true location – within 5 metres even though the errors in the data are an order of magnitude larger.

If the errors are truly random, then the best estimate of the true location of the line feature is a line of best-fit. There are well-known methods for computing a line of best-fit using statistical means such as least-squares analysis or adaptive filters. However, most of these automated methods do not work well with GPS data under forest canopy, and usually will create a best-fit line which has significant systematic errors.

Operationally, a subjective best-fit line is usually drawn by an operator using the GPS-derived line feature as a guide. With a bit of knowledge, experience, and especially common sense, a human operator can produce a subjective best-fit line which is a much better estimate of the true location than automated statistical methods available to date.

Figure 5.28  An example of random errors in line features (actual data)
5.8.4 GPS Under Forest Canopy

The effects of forest canopy can significantly degrade the accuracy of GPS positions (Fig. 5.29). The signals are affected by the canopy and this of course affects the quality of the computed position. Forest canopy effects on the GPS signal include obstruction, attenuation, and reflection.

*Figure 5.29  An example of the impact of forest canopy on GPS signal reception.*

The GPS signal is a line-of-sight signal and is obstructed by most solid objects. The signal is blocked by the trunks of trees, larger branches, and terrain features such mountains or local gullies. The main effect of signal obstruction is to increase the Dilution of Position. This is especially true of the vertical DoP (VDOP) – and hence the three dimensional PDOP. Often in forested conditions the HDOP is acceptable when the PDOP is not.

The signals are weakened or attenuated by leaves and small branches. This attenuation can make it very difficult for a GPS receiver to track the signals. At some point, the receiver will not be able to track the signal at all and the effect will be the same as if the signal were obstructed. Even if the signal can be tracked, some receivers will have difficulty accurately measuring the pseudoranges.

Like light waves, signals will be reflected by solid objects they cannot pass through. The phenomenon of a satellite signal reaching an antenna by more than one path (direct and some reflected paths) is called multipath. This multipath can cause large variations in position and is perhaps the largest cause of large errors in position fixes under forest canopy.
**Stand Conditions and GPS Data Quality**

Naturally, forest stand conditions have a very important effect on the errors in GPS positions. The testing done to date has been limited to coastal conditions, but canopy conditions vary widely throughout the test range. Some stands are very high volume coastal stands, and others are more typical of interior conditions (some testing in the interior is planned). High-density immature stands, forest fringe conditions, coastal riparian zones, and entirely open conditions are also present throughout the test range.

For all receivers tested, volume seems to be much more of a factor than density or canopy closure. The large trunks obstruct the signal, meaning that often there are not enough satellites for a position fix or the dilution of precision is too high. This means far less position fixes for point and line features. Even though there are maximum allowable gaps, there will be much less redundancy. It will be more difficult to create interpreted lines because there are less fixes to act as a guide – it is also more difficult to assess the overall quality of the data.

Signal reflection from the large trunks and branches in high volume stands is also a problem. The data is far more suspect to multipath effects which can often cause positions to be tens of metres or more out – this is especially a problem with point features, as explained in section 5.8.4.

In dense, immature stands even though crown closure can be significantly higher, most receivers seem to track signals well enough. In these cases, data noise (random error) is the main problem.

The GPS signal is absorbed by water molecules which means that if there is moisture in the leaves (especially standing water on the leaves during or after heavy rain), there is much more attenuation of the signals. Wet canopy conditions mean that it is very difficult for the receiver to track sufficient signals, and like in high volume conditions, there will be fewer fixes and hence less redundancy. Again, field operators will ensure that there is sufficient data, but it is much more difficult to interpret the lines in the mapping process.

**Handling Errors in Static (Point) Features**

Conventional wisdom has it that averaged point features are inherently more accurate than dynamic line features. This is certainly true in ideal, low-multipath conditions. If a line is sufficiently straight that it can be
defined as a line connecting two points (for example a curb line), it may be more accurate to collect it as a series of points.

However, under moderate to heavy forest cover, all receivers tested to date have been less accurate in static mode than in dynamic mode. This is because the systematic effect of multipath is much more pronounced when the antenna is static. The geometric relationship between the satellites, the GPS antenna, and the interfering trees and leaves does not change appreciably over short time periods. Simple multipath effects in GPS follow a well-known cycle of around 8 minutes and long occupations are required to ensure that the errors average out during a static point feature.

Although not all point features under canopy are subject to systematic errors, all features should be examined carefully and the errors resolved satisfactorily. Plotting the individual position fixes for point features usually helps greatly in identifying systematic errors, although most GPS software does not provide this information (the MoF has developed some tools to access this information from common software). If there is dynamic data available (for example bridges along a trail or falling corners on a cutting boundary), systematic errors will also be evident when the averaged point is not on the line as expected.

Figure 5.30  Systematic Errors in Static Point Features (actual data)

Figure 5.30 shows typical multipath characteristics for three different points. One thing that is noticeable with most receivers is the trend to the systematic errors. There is a noticeable wander to the points – it is often as if the operator slowly walked a line during the static occupation. Although this phenomenon is not universal, it is probably the best indicator of problems with point features.

If trends are noticeable, the true location of the point feature usually lies somewhere along the trend line. When there is supplementary information (e.g. a dynamic line survey which the point is expected to be on), the most likely location is where the trend in the point fixes meet the
dynamic line feature. For surveys where there are point features only, it is often better to stay longer at points, or do two occupations separated by a few minutes.

A field procedure, which may help to minimize systematic errors, is to move the GPS antenna around slightly during static occupations. Under forest canopy, where tree trunks and branches are the main cause of multipath, this technique can cause the multipath effect to become more random than systematic. Recently (March 2000), a very limited preliminary test gave encouraging results for this method, but more extensive testing is required before any conclusions can be made.

Figure 5.31 Resolving Systematic Errors in Point Features (actual data)

Handling Errors in Dynamic (Line) Features

Dynamic line features under forest canopy can have significant random, systematic, and gross errors. Normally, the errors in line features are predominately random, with perhaps a few easily identifiable gross errors. This is because, contrary to static surveys, the antenna is constantly moving and the multipath conditions are constantly changing. The systematic effect is usually of quite short duration and only affects a few metres of the line feature. Large homogeneous features such as rock faces or building walls can cause systematic error in dynamic features.
over longer sections.

**Figure 5.32 Minor Random Errors in Dynamic Line Feature**

Figure 5.32 shows typical performance of a well-known receiver under moderate canopy conditions. The errors are usually random and quite small (usually less than 5 metres). What systematic errors there are quite minor, being less than 5 metres in magnitude and having a short period, rarely lasting for much longer than 10 metres. With this receiver (the most commonly used for forest surveying) it is quite easy to reliably assess the data quality visually.

Figure 5.33 shows the performance of a different receiver under exactly the same conditions (this receiver is not common in forestry surveying). The errors, while large, are mostly random also. There are quite a few gross errors (zingers) which should be easy to reject. There are some systematic errors, especially in the lower section and where the lines meet in the bottom right. These errors are fairly small (less than 10 metres), and occur for short periods. Overall, the data is quite noisy and in some places requires a leap of faith to create an interpreted line. It is acceptable however, and visual quality assessment methods will identify any problems.

**Figure 5.33 Significant Random Errors in Dynamic Line Feature**

Some GPS processing software programs attempt to perform some automatic line smoothing. The basic assumption is that line features should not be extremely jagged or noisy – natural and man-made linear features such as creeks, trails, or cutting boundaries do not usually
resemble a row of saw teeth. Smoothing filters are usually proprietary and cannot be disabled in the software.

Line smoothing will almost always cause some systematic error in the line feature at the processing stage. This is because any smoothing or curve-fitting algorithm must make certain assumptions about the nature of the errors in the data, and the general shape of the resulting smoothed line – these assumptions are not likely to hold for GPS data under forest canopy.
In most cases, the systematic errors will be small in magnitude (5–10 metres), and short in duration (less than about 20 metres) – such errors may be marginal but acceptable under the stream mapping specifications (5m dynamic accuracy, 95% of the time). The data looks good initially, and visual quality assessment will usually not suggest any problems – that may require a re-survey. In the case of this receiver the main clue to the systematic nature of the errors (other than the receiver brand) is the short period of the errors, and the “wows” they make in lines which should be straight or less convoluted.

The above example shows significant systematic error. This receiver consistently shows these errors, and it is being used by a small number of organisations for surveying under forest canopy in BC. The data is often significantly (more than 10 metres) in error for sections of 50
metres or more, even though at first glance, the data looks fine with little noise and lots of redundancy. Clues to these errors include inexplicable shifts in the data, where a smooth line suddenly moves a few metres to another smooth line, as if the field operator was walking along an offset line. Sharp bends in the line, and mismatches where lines should join are other indicators of significant systematic errors in line features.

**Common Errors Due to Operator Interpretation**

The editing and interpretation stage is perhaps the most important step in a GPS mapping survey. It is at this stage that data quality is assessed, and that errors are identified and corrected. If the data is not good enough to meet project specifications, it should not make it past this stage.

The interpretation stage is where final decisions about the quality of the data are made. After this step, the product becomes a map which is generated using GPS data, but does not usually contain any actual GPS data – the edited and interpreted lines and points have no quality information associated with them. The Standard GPS Quality Assurance procedures described in section 8 compares the generated lines and points on the map with the original GPS data, but these procedures would only be applied on a portion of the entire project.

The interpretation is usually done by mapping operators with a good knowledge base of the nature of errors in GPS positions. However, not all operators have the required training and experience, and some may make errors which, although they do not affect the quality of the GPS data, they certainly affect the quality of the final map.

Because of the possibility of interpretation errors (actual problems with the linework or not properly correcting errors in the GPS data), the QA procedures consider both the GPS data quality and the quality of the interpretation.

Common interpretation errors include:

- Consistent mis-interpretation of data noise. This is not common, but can cause significant systematic errors, especially in area calculations. This error becomes immediately obvious during QA as the interpreted line does not make much sense given the underlying GPS data.
- Mis-identifying errors in field procedure as boundary features. For example, field operators may inadvertently collect GPS
data when they are wandering about looking for the beginning of a ribboned line to be surveyed or a cruise strip to be tied (or perhaps even looking for a good log for a bathroom break!). To experienced operators, these field errors often look like anomalies in the feature, but some mapping operators will assume they are part of the feature.

- Following noisy GPS data too closely. This is a common mistake of inexperienced operators who are trying to be conscientious, and who sometimes do not realise that natural features are not so convoluted. This can be avoided by using some sort of scale reference to constantly remind the operator the distances involved – for example the 10 metre diameter circles included in many of the examples in this section. Although this is not strictly an error, it does make the interpreted line look strange to most observers, and can cause errors in such derived quantities line length (which would report as being longer than it really is).

- Ignoring large gaps in the data. Especially in difficult conditions, some gaps in the data will be unavoidable. If the gaps are greater than 25 metres, mapping operators should ensure that line features are straight before drawing straight lines across the gaps. The temptation may be to just sweep the gaps under the rug, however, most interpretation errors can be minimised by having others, especially field personnel and more experienced mapping operators, review the data before submitting it.

### 5.8.5 Integrating Conventional Survey Data

There may be many instances where conventional survey data must be integrated with GPS data. It may be that a fill-in survey (see 5.6.2.) is required where terrain and forest cover conditions mean that GPS is very difficult. In some cases, GPS positions might be used only to control surveys done with compass and tight-chain. This is especially true for stream mapping scenarios, especially where expensive GPS equipment is not always available, and where deep-forested gullies are often encountered.
5.9 GPS Data Processing

5.9.1 Handling GPS Data Using Pathfinder Office And ArcView

This document is intended as a set of suggestions on how to most effectively collect stream mapping data with Trimble receivers into ArcView. It presumes that users are familiar with both software packages, especially ArcView (since GIS software typically require much more training than simple GPS softwares such as Pathfinder Office).

Both the features (points and lines) and the individual position fixes should be exported. Just exporting the features, which is the default mode of Pathfinder Office (and most other GPS packages) is not sufficient as operators cannot identify gaps in the data, systematic errors in point features, etc.

To export both features and fixes in Pathfinder Office, two separate export operations, with two different export configurations, must be run.

1) Setting up the Export Options

To create the export setups, first use the New Setup button to create a new export setup with a descriptive name such as "ArcView Features". The following options will probably be the system default – if not, change them so that Export All Features is selected.
Note: Under the Attributes tab, the user can add such useful information as average PDOP for features, number of fixes in the feature, or standard deviation for point features. These will become attributes in the ArcView table, and can be queried or displayed in ArcView.
The Position Filter tab allows the user to filter out positions which do not meet certain standards – for example if some “2-D” (less than four satellite) data was collected in the field which needs to be filtered out before export. Of special note here is that, with Selective Availability (S/A) off since May 2000, it is often difficult to tell corrected from uncorrected data. Even though uncorrected data might look good or smooth, even to an experienced user, the positions can be out by over 10 metres for long periods. Users should always ensure that the Uncorrected option is not chosen.

Note: the Filter By Precision option is not really an indicator of data quality, especially under forest canopy. It seems to correspond almost exactly to the HDOP at the reference station (using 95% confidence), nothing more.

Finally, the Coordinate System tab should be used to ensure that the data exported can be brought into ArcView in the proper location. If the GPS data does not fit with base information such as existing maps or orthophotos (or even other GPS data), this is almost always the reason.

In most cases, the UTM map projection (in the appropriate zone) is used. In some instances – especially when using GIS data from the BC Ministry of Environment, the BC Albers Projection must be used. This is not included in Pathfinder Office’s list of coordinate systems. If the BC Albers
projection is necessary, use the Coordinate System Manager (*Utilities – Other – Coordinate System Manager*). Create a new group if necessary with a name such as “Custom” (*Edit – Add Coordinate System Group…*) and then add the BC Albers projection to the new group (*Edit – Add Coordinate System… – Albers Equal Area Conic…*). The Projection screen should look like this:

![Projection Screen](image)

**Note:** that other options such as *Datum* and *Geoid Model* are set up here also. The datum transformations and geoid models provided with Pathfinder Office are approximate only, and not accurate enough to meet the 5 metre accuracy requirement. Unless they have been thoroughly tested in the local area, these conversions should never be used. NAD 83 (or WGS 84) and *No Geoid Model* are the only acceptable choices here. If other datums or orthometric heights are required, more accurate
transformations (such as available from Geomatics Canada) should be used.

Next, create a second setup to export the GPS position fixes only. Create a new setup with a name such as “ArcView Fixes”. If the “ArcView Features” setup above is currently chosen, the system will create a copy of that – the only change will be to rename the setup and to change the “Type of Data To Export” from Features to Positions Only, as shown below.

2) Exporting Data

To export data to ArcView, the export routine must be run twice using the two setups created above. The setup is chosen through the list box.  

![Export Routine Screenshot](image)

The export routine will create a series of files for each feature type, and for the fixes. There will be a shapefile *.shp, an index file *.shx, and a database table *.dbf. These files will have a prefix relating to the name of the feature, for example “Point_Generic” or “Stream Centreline”. The file for the point fixes will always have the prefix “Posnpnt”.

Pathfinder Office will export these files to the folder indicated under Output Folder. If there are files with the same name there, they will be overwritten. This may be a problem if, for example, GPS files are
exported daily throughout a project – the last day’s data will be continuously overwritten. Users should develop some system to manage these files, either by renaming files, creating separate directories for each export operation, or merging files.

**Note:** that, when the export routine is run the second time to obtain the fixes, a warning message about overwriting files will usually be generated. If the above problem is properly handled, this applies only to an information file and the warning can be safely ignored.

**3) Importing into ArcView**

Since the data is exported in many different shapefiles (one for each feature type and one for the position fixes), they must all be loaded into ArcView. The important thing is to ensure that the position fixes are shown, and in a way that data quality can easily be assessed.

To import data into ArcView, use **View – Add Theme**. Multiple themes can be chosen by using the SHIFT key and the mouse.

The features will be shown by default symbols. These should be changed to make the display easier to understand – especially the fixes and line features. Double-clicking on the theme in the legend will bring up a symbol editing menu. Although users may find other symbols preferable, the following have been found useful:

<table>
<thead>
<tr>
<th>Feature</th>
<th>Symbol</th>
<th>Size</th>
<th>Colour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posnpts</td>
<td>cross or “X”</td>
<td>4 point</td>
<td>bright</td>
</tr>
<tr>
<td>Lines (various)</td>
<td>dashed</td>
<td>0.1</td>
<td>various</td>
</tr>
</tbody>
</table>

**Note:** themes can be displayed based on their attributes as well. This can be very useful in displaying position fixes based on, for example, PDOP (as a quality measure). It can also be used to show individual line features during the data interpretation phase (discussed below). The
following screen capture shows a typical survey area using the above display parameters.

4) Setting up for Data Interpretation

The data interpretation stage is the most important stage of all. This is where the errors in the GPS data (usually due to the effects of forest canopy) are assessed. If the data is not good enough, sections can be re-surveyed.

If the data meets specifications, the errors must be smoothed to resolve the remaining random and systematic errors. If this interpretation of the remaining errors is not done, further display and analysis is not possible. In the example above, canopy effects cause much back and forth in the line features – any query such as “how many metres of riffle habitat are there on the stream” would obviously be very far out. Also, the point feature (circle symbol) towards the bottom of the screen has obvious systematic errors and must be brought back to the line.

During this stage, it is essential that the operator is always aware of distances on the screen. One way to do this is to place circles of a certain diameter (e.g. the accuracy specification) along the line. Using circles, the orientation of the fixes is not important, as the scale is obvious in any direction. This technique helps ensure that operators are not
generalising too much, nor are they zooming in too much and spending
time on errors, which are much less than the accuracy specification.

Circles are placed as graphic objects, using the circle tool. This, however,
is quite cumbersome, as the circle must be placed interactively. The
following Avenue script can be used to create a tool which will place a 5
metre diameter circle (2.5 metre radius) at a location the user clicks. Feel
free to enhance the script.

ArcView Avenue Script
--------------------------------------------
'place_circle.ave
'simple script to place a 5m diameter circle at selected
point
'used for GPS data interpretation scale circles
'to use, create a tool for this in the view
'steve robertson, 2000  (stever@mindlink.bc.ca)

'get cursor position in active view
curView = av.GetActiveDoc
curDisplay = curView.GetDisplay
userPoint = curDisplay.ReturnUserPoint

'build the circle
activeCircle = Circle.Make(userPoint,2.5)
 'change for different diameter
graphicCircle = GraphicShape.Make(activeCircle)
aSymbol = BasicPen.Make
aSymbol.SetColor(Color.GetRed)
 'change for different colour
graphicCircle.SetSymbol(aSymbol)

'place the circle at cursor
curGraphics = curView.GetGraphics
curGraphics.Add(graphicCircle)
--------------------------------------------

5.9.2 Editing GPS Data Using the Data Dictionary Tool
Extension for ArcView

The Data Dictionary Tool Extension was developed for the post-
processing of GPS data and the creation of new data from different
mapping sources. The extension is intended for use for the creation of a
new stream line theme from GPS data and point themes from
documentation or other point themes. This document provides
instructions in the use of the extension tool. Users should have basic ESRI ArcView or ArcINFO experience.

Current SHIM methodologies involve the use of differential GPS to collect and store spatially accurate information on line, point and polygon features of watercourses. Correct interpretation of the raw GPS inventory data involves a series of post-processing steps that may be undertaken within a variety of computer software packages. To simplify this process and to allow SHIM mappers to more easily interpret their collected stream information, the Data Dictionary Tool was developed as a customized ArcView extension for post-processing raw GPS inventory data. The Data Dictionary Tool also contains a series of features for easily creating, editing and merging ArcView shape files that will assist in minimizing project size and will facilitate map data management. In addition, there exists a wealth of historic SHIM data collected prior to the widespread use of the Trimble GPS units. The Data Dictionary Tool was developed to provide a means for linking this archived SHIM point data to newly derived stream linework collected in accordance with current GPS standards for spatial accuracy. In summary, the Data Dictionary Tool Extension provides a means to: 1) manually correct stream linework derived from GPS datapoints, 2) link previously derived GPS point data to new stream linework using unique ids, 3) create and merge common shapefile themes, 4) incorporate archived hard copy or electronic spreadsheet data into current SHIM data formats, and 5) create digitized polygons of riparian habitat. This guide will provide step-by-step instructions in the application of the Data Dictionary Tool and is designed for the basic ArcView user.

Loading the extension in ArcView

- Copy the ddtool.avx file provided into the Ext32 subfolder on your computer hard drive
  (C:\Esri\Av_gis30\ArcView\Ext32)
- Open ArcView with a new project and in the project file menu go to File > Extensions, select the Data Dictionary Tool 1.0 extension and click OK.
- Loading the extension will add new script, view and dialog documents to the project. In the project window select the
views document and open the Edit View by double-clicking on it.

Edit View contains all the tools for manipulating GPS derived data and creating new point and line themes. There are also tools for linking and merging themes with the same feature type.

Creating a new interpolated stream line

1. In the Edit View window’s button menu click on the Add Theme tool and add a GPS derived line theme (e.g., streamdy.shp) to the view.

2. Click on the Interpolate GPS Line tool and a dialog will appear. Provide a name for the new stream line theme and click OK.

3. Another dialog box will appear prompting for the GPS derived line theme in the Edit View to copy attributes from. Select the appropriate theme (e.g., streamdy.shp) and click OK.
The Line Edit Tool will appear and the GPS derived line theme will now be colour coded based upon existing segment breaks.

4. Click on the Draw Circle Buffer tool and click on locations in the view window to draw a series of 5m diameter red circles along the stream length. Use the Zoom In/Out tools within the Edit View window to zoom down to a view of the stream at which you can clearly delineate the boundaries of the buffer circles. These buffers will assist in the determination of the line of best fit during the line drawing process. A recommended suggestion would be that 300–500 meters of stream be visible within a single screen view (approximate scale of 1:2500) to ensure accurate interpolation of the stream line.
5. Click on the Draw Line tool and digitize a new best fit line theme based on the GPS derived line and circle buffers.

6. Click on the Split Line tool to insert segment break points or vertices in the new line theme.

7. After all segment breaks are accounted for, click on the Copy Attributes tool to copy the original attribute data from a GPS derived line segment. Then click on the Paste Attributes tool to paste the copied attribute data to a new line theme segment.

8. Continue copying and pasting line segment by line segment. When all attributes have been copied fully to the new line theme, click on the Save button to save all edits.
Linking point data to a stream line theme

9. Ensure that a stream line theme and at least one point theme exists in the Edit View window.

10. In the Edit View window’s button menu click on the Link Themes Tool to create a unique ID based on the stream name and TRIM mapsheet number.

11. In the Add Index Theme dialog that appears, browse to where the provided index theme (trimgridp.shp) is located and click OK. This dialog appears only when the Link Themes tool is used for the first time.

12. In the Select Line Theme dialog that appears, select the appropriate line theme for linking and click OK. A new field named “Key_ID” will be created in the line theme.
13. In the Select Point Theme(s) dialog that appears, select the appropriate point theme(s) for linking and click OK. A new field named "Key_ID" will be created in the point theme(s).

14. In the Stream Name dialog that appears, use the default name or enter a new name for the stream to be used in the unique ID and click OK. The stream name "test" is used as the default.

15. Another dialog will appear displaying the unique ID and prompting the user for validity. Click YES to continue. If the unique ID exists already (e.g., line theme already contains a different unique ID) a dialog will appear prompting for either the use of the existing ID or replacing it with the new one. The default is NO.
Merging themes together

16. In order to use the Merge Themes Tool more than one theme of the same feature type must exist in the Edit View window.

Click on the Merge Themes tool in the Edit View’s button menu. In the Input Theme dialog that appears, select one theme to be used as the template for the creation of fields. That means a field not contained in the template will not be merged into the resulting theme.

17. The Themes to Merge with... dialog box will appear showing themes in the view window that are of the same feature type. Select the appropriate themes and click OK. Another dialog box will appear prompting for the name and location of the newly merged theme. Enter the appropriate information and click OK. The merged theme will be automatically added to the Edit View window.
Creating or updating SHIM data points

The SHIM data entry options included with the Data Dictionary Tool extension can be used for recording and mapping of new point data. In general, however, this information is now more reliably collected and recorded directly in the field using high-end GPS receiver units and associated data loggers. The primary role of the SHIM tool is instead to allow incorporation of data from other sources (e.g., archived hard copy documents) into formats compatible with existing SHIM data structure and spatial mapping. A different tool dialog box can be brought up for each of the different point data types (e.g., culverts, cross-sections, obstructions, etc.) for which SHIM information is currently collected. Data entry options within each data type are identical to those currently existing within the SHIM Data Dictionary (Version 23) that has been developed for use with the Trimble Pathfinder GPS. The only exception to this relates to the normal SHIM entries for riparian bands; due to size limitations a tool for riparian bands has been excluded from this extension.

1. In the Edit View window’s file menu go to SHIM Data and select the desired SHIM data tool to create your new points.
2. A Point Tool dialog box will appear indicating the required cells for data entry. Enter the appropriate information in each cell. Then click on the Add Point Tool and place the accompanying cross-hairs on an selected area of your view (e.g., correct location on a mapped stream) to create a new point feature with its associated attribute data.
After entering the required information and creating a new point, click on the Save As button to save the point as a new shape file. This will automatically add the file to the Edit View window.

3. After creating single shape files for each point of the same data type (e.g., individual erosion points), all the saved points should be merged together into a single theme (e.g., pooled erosion points theme). To do this use the Merge Theme tool and associated methods outlined in section D.

4. To link the newly created SHIM data points to a mapped stream line use the Link Theme tool and associated methods outlined in section C.

Creating riparian polygons

The SHIM Data extension can also be used to delineate riparian habitat polygons adjacent to mapped streams. Data cells within the Riparian Polygon Tool can be populated by habitat information collected directly in the field or else interpreted from photogrammetric analysis of underlying orthophotos. The Confidence data cell allows for a qualitative assessment (low, medium or high) by the user of the relative accuracy of the riparian classifications for the polygon.

1. In the Edit View window’s file menu go to SHIM Data and select the Riparian Polygon Tool to create your new habitat polygons.
The Riparian Polygon Tool dialog box will appear indicating the required cells for data entry. Enter the appropriate information in each cell.

2. Then click on the Add Polygon Tool and use the accompanying cross-hairs to create the lines and vertices of the habitat zones you wish to define within the selected area of your view. The process will create a new polygon feature with all its associated attribute data. If available, it is recommended that an underlying orthophoto image of the area be imported into your ArcView project. This will greatly enhance the ability to accurately delineate the boundaries of riparian habitats. Acquisition of current orthophoto coverages is the responsibility of the user, and can be obtained through various regulatory agencies (e.g., FOC, GDBC, municipal governments)
4. After entering the required information and creating a new polygon, click on the Save As button to save the polygon as a new shape file. This will automatically add the file to the Edit View window.

5. After creating single shape files for each riparian area the polygons can be merged together into a single theme (e.g., riparian habitats). To do this, use the Merge Theme tool and associated methods outlined in section D.
5.10 References Cited

British Columbia Standards, Specifications and Guidelines for Resource Surveys using GPS Technology:
http://home.gdbc.gov.bc.ca/gsr/gsr_standards.htm

Geographic Data BC Website: http://home.gdbc.gov.bc.ca/

Geological Survey of Canada Website: http://www.nrcan.gc.ca/gsc


Ministry of Forests GPS Steering Committee: http://www.for.gov.bc.ca/lsb/gps

Natural Resources Canada Website:
http://www.geolab.nrcan.gc.ca/geomag/e_cgrf.html

Terrapro GPS Surveys Ltd Website: http://www.terrapro.bc.ca

US CORS system Website: http://www.ngs.noaa.gov/CORS
