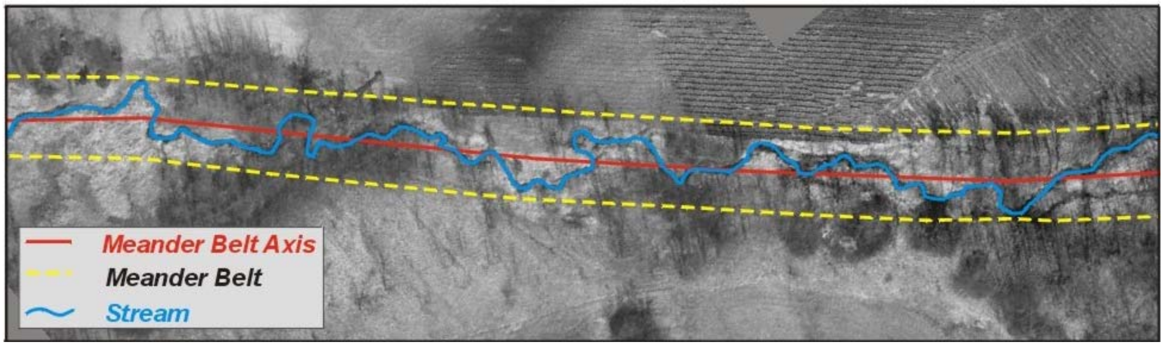
Belt Width Delineation Procedures



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Introduction

1.1 Overview

In recent years the meander belt width has been suggested as a tool for managing risk to life and property from river erosion while at the same time protecting the long term integrity of the watercourse and its aquatic habitats. Because a watercourse is expected to move and change within the meander belt, anything situated within it could, at some time in the future, be subject to erosion by the channel. Thus, the meander belt as a tool for planning purposes is a valid approach for defining the area in which river processes occur and will likely occur in the future.

The meander belt width is typically contained within the regional flood plain and does not address geotechnical, slope stability issues. Thus, the meander belt width is not a substitute for flood lines or geotechnical setbacks to define the limit of development. However, where some types of development or activities are to be contemplated in proximity to a watercourse, the meander belt width can be an important planning tool.

Specific applications for the meander belt width delineation include:

- Subwatershed studies
- Siting of stormwater management facilities
- Planning for trails, golf courses and other resource based uses.
- Stream re-naturalization

The purpose of this report is to recommend a protocol for the delineation of meander belt width for watercourses within the jurisdiction of the Toronto and Region Conservation Authority. Since the development of a meander belt width protocol must consider the physical processes that occur along a meandering watercourse, as well as the context and scale at which the meander belt will be used, several different procedures have been devised.

For most of the procedures outlined in this document, the belt width delineation process can be completed using topographic maps and aerial photographs.

1.2 Organization

This document is divided into four main sections. **Chapter 2** presents relevant general background information on meandering rivers and their migration tendencies, to give the practitioner an appreciation of fluvial processes as they pertain to the meander belt. More specific information is provided in **Appendix B**. **Chapter 3** outlines and describes the general methods and preparatory work required prior to quantifying the meander belt. **Chapter 4** contains a description of ***Procedure 1*** in which only a general notion of the meander belt position and width is required (i.e., typical for subwatershed studies). Procedures that enable an accurate quantification of the meander belt are outlined in **Chapter 5.** ***Procedure 2*** is intended for the situation in which no change in hydrologic regime is expected; ***Procedures 3 – 4*** when a change in hydrologic regime is anticipated; ***Procedure 5*** describes the process that should be undertaken when the watercourse has been altered, no reliable historic information of its natural form or of a surrogate reach is available. The procedures are presented beginning with the most general application and gradually increase in complexity to address the more specific needs for belt width delineation. An example, illustrating the application of the methods, accompanies each procedure.

It is the intent of this document to include as many different scenarios as possible to account for the different situations and conditions that may be encountered while applying the belt width delineation procedure. Nevertheless, due to the inherent natural spatial variability in channel form and setting that can occur, even within the area that is under the jurisdiction of the Toronto Region Conservation Authority (TRCA), it is not possible to represent all the settings and variations of the meander belt application within this document.

It is recommended that appropriate technical experts be consulted when adapting these procedures to scenarios that are not specifically addressed in this report.

Chapter 2

Background Information and Context for Belt Width Measurements

2.1 Introduction

Creeks and rivers are dynamic features on the landscape. Through time, their configuration and position on the floodplain changes as part of meander evolution, development, and migration processes. When meanders change their shape and shift in their position, the associated erosion and deposition that enable these changes to occur, can cause loss or damage to private properties and/or structures. For this reason, when development or other activities are contemplated near a watercourse, it is desirable to designate a corridor that is intended to contain all of the natural meander and migration tendencies of the channel. Outside of this corridor, it is assumed that private property and structures will be safe from the erosion potential of the watercourse.

The space that a meandering watercourse occupies on its floodplain, and in which all of the natural channel processes occur, is commonly referred to as the meander belt. Other terms that have been used to describe these concepts include meander width, belt width, and river corridor (Gurnell, 1995). For planning purposes, the width of the meander belt (i.e., meander belt width) is of interest since it defines the area that the watercourse currently occupies or can be expected to occupy in the future.

Watercourses are dynamic systems and, to enable the non-river scientist to apply the belt width delineation procedures that are presented in this document, it is appropriate for the practitioner to gain a general appreciation and understanding of relevant fluvial processes. For this reason, this chapter gives a general overview of river features and processes that are pertinent to the definition of a meander belt. A glossary containing various geomorphic terms has been placed in **Appendix A**. More detailed information which has been subjected to a peer review, along with relevant references from the scientific literature, are in **Appendix B**. Information presented in this chapter is sufficient to provide a general context for the different belt width delineation procedures that have been developed. Further, the terminology and concepts that are discussed will enable effective communication between practitioners and regulatory agencies regarding fluvial processes as they relate to the river corridor.

2.2 Planform

The planform of a watercourse refers to the meandering pattern that can be readily observed on topographic mapping and aerial photography. There are four broad classifications of planform patterns including: straight (i.e., low sinuosity), meandering, braided and anabranching. In Southern Ontario most, if not all, watercourses fit within the first two of these categories. The natural meandering pattern that occurs along a watercourse is a result of the interaction between the water and sediment regimes that are conveyed to, and through, the channel and the physical characteristics of the setting in which the watercourse is situated. Some of these factors, as identified by Chitale (1970), Shahjahan (1970) and Schumm (1985) include:

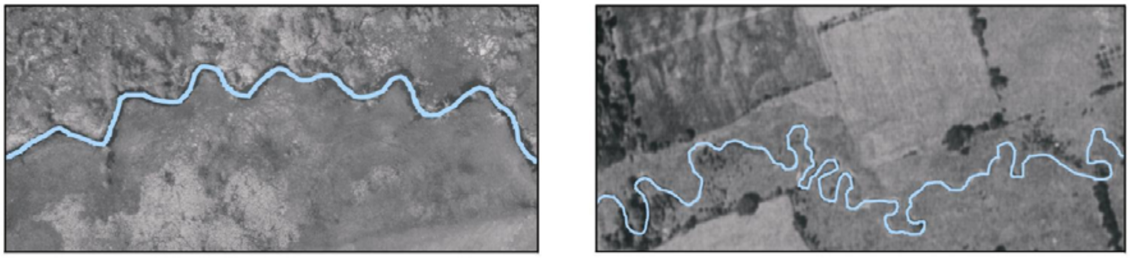
- Flow regime (magnitude, frequency, duration and dominant discharge);
- Floodplain materials (surficial and bedrock geology);
- Width: depth ratio of channel;
- Sediment (supply, load – suspended, mixed, bed, transport, type - coarse vs fine);
- Valley gradient;
- Riparian/floodplain vegetation

Due to an inherent spatial variability of these factors, planform patterns will vary between adjacent watercourses and along the drainage network of a specific watercourse. Further, temporal variability in these factors can occur through time and may be a consequence of natural changes (e.g., climate; movement of channel to more/less erodible floodplain materials) or may be induced by human activity (e.g., change in flow regime due to urbanization and storm water management).

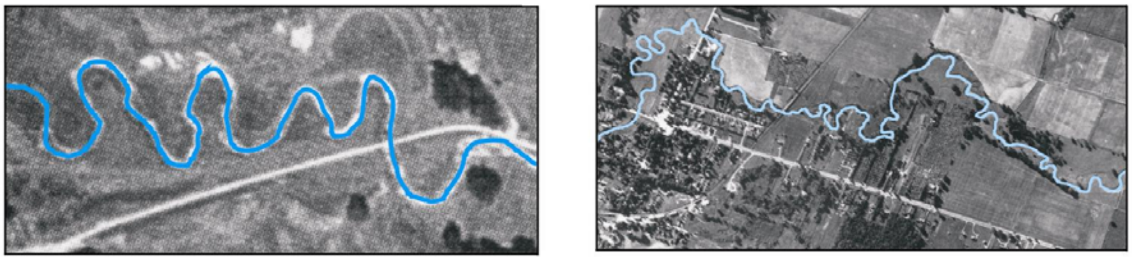
Regardless of the cause, whenever one or more of the factors that influence channel pattern is altered (spatially or temporally), then an adjustment in planform is expected to occur. These adjustments are part of a natural process wherein the channel works to develop a configuration that will maximize efficiency of water and sediment conveyance while at the same time minimizing the work that is required to move the water and sediment downstream. The rate and type of adjustments that can occur along a meandering watercourse in response to a change in one of its influential factors are discussed in the proceeding sections.

2.3 Meander Geometry

In addition to the three broad classifications of watercourse pattern, the meander configuration can be further described as regular or irregular, and as simple or compound (Chitale, 1970). A *regular* meander pattern implies that all meanders in a sequence of meanders are similar in radius, shape and frequency; ***irregular*** refers to variability in each of these parameters **(Figure 2.1).** In general, *regular* meanders occur when floodplain materials are relatively homogeneous with respect to composition and erodibility. When the floodplain contains lenses, strata or deposits of resistant material, then the meander pattern tends to become *irregular*. Meander patterns and individual meander bends are, most often, characterized by asymmetry and irregularity (Carson and Lapointe, 1983; Hooke, 1984). ***Simple*** meanders consists of a single downvalley direction whereas ***compound*** meanders are essentially two meander patterns that are superimposed on one another (Chitale, 1970) **(Figure 2.1)**. The occurrence of *simple* or *compound* meanders is linked to the discharge that exerts the most influence on channel form (i.e., dominant discharge, see glossary for distinction between bankfull and dominant discharge). A *simple* configuration occurs when only one discharge influences channel form; a *compound* configuration occurs when more than one discharge influences channel form. In some instances, the compound pattern may be driven by glacial paleo-channels, especially within wide, unconfined valleys. Researchers of meander configurations have often approached their study by describing meander patterns as a mathematical sine wave function or a variation thereof. The planform variability of Southern Ontario provides various examples of regular and irregular, and of simple and compound planform patterns.



Regular Meander Pattern **Irregular Meander Pattern**



Simple Meander Pattern **Compound Meander Pattern**

Figure 2.1: The Meander pattern of a watercourse can be described as regular or irregular, and as simple or compound.

To enable discussion and analysis of a planform, various components of one, or a sequence, of meanders have been identified (e.g., wavelength, amplitude, radius of curvature, sinuosity, meander belt, **Figure 2.2**). Analysis and investigation of meander properties led Leopold and Wolman (1960) to observe that the meanders of all rivers tend to be scaled versions of the same set of geometric variables. Shahjahan (1970) stated that even the smallest watercourses have a planform resemblance to larger natural systems. Based on planform research, it appears that relations between different elements of the meander configuration appear to be independent of scale since they are conserved as meanders change in size. This observation is confirmed by the fact that empirical relations that predict meander geometry variables from another meander variable or from a channel dimension or discharge are statistically significant (see for example: Williams, 1986). An exception to this generalization is in the predictive relations that involve meander amplitude since these are most often weak. Most often, when poor correlation among meander properties occurs, then this is likely due to the strong control of stream bank erodibility and other factors in controlling meander size (Leopold and Wolman, 1960; Shahjahan, 1970).

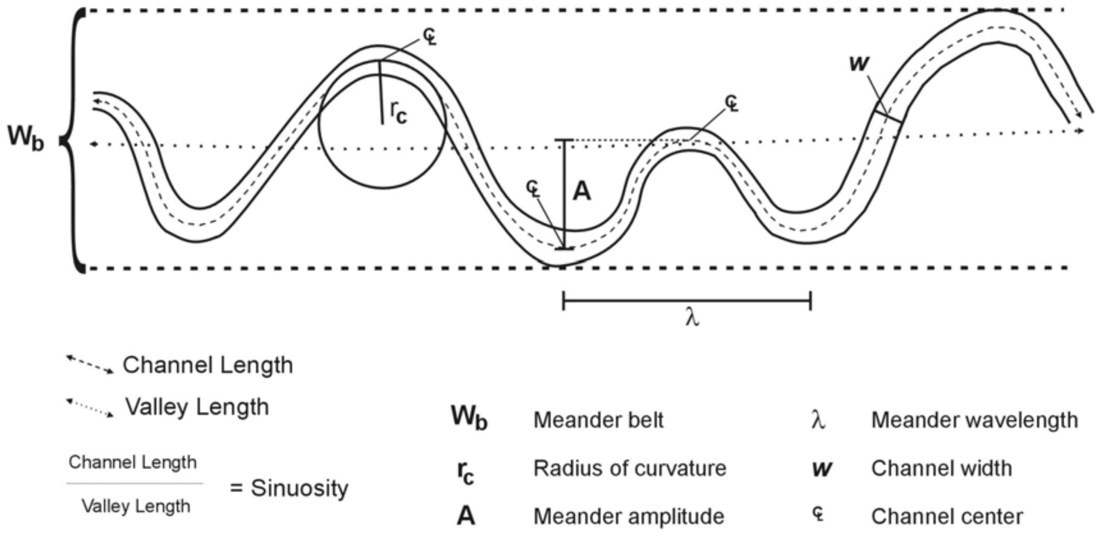


Figure 2.2: Schematic identifying terminology used to describe different components of the meander planform.

2.4 Meander Belt versus Meander Amplitude

Both amplitude and belt width are terms that quantify the lateral extent of a river's occupation on the floodplain. Because the distinction between meander amplitude and meander belt width is not always clear, a brief discussion is appropriate. Leopold et al., (1964) define meander amplitude as the lateral distance between tangential lines drawn to the centre channel of two successive meander bends **(Figure 2.2)**. Therefore, the amplitude is measured only between successive meanders (i.e, from a meander crest to a meander trough or vice versa). The meander belt is measured for a reach between lines drawn tangentially to the outside bends of the laterally extreme meander bends in a reach **(Figure 2.2).**

Even when one meander bend essentially defines the meander belt, the quantifiable amplitude is always smaller than the belt width. This is because amplitude is measured from centre channel to centre channel in successive bends, and the belt is measured from the channel banks on the outside of the meander bend (i.e., concave bank) **(Figure 2.3).**

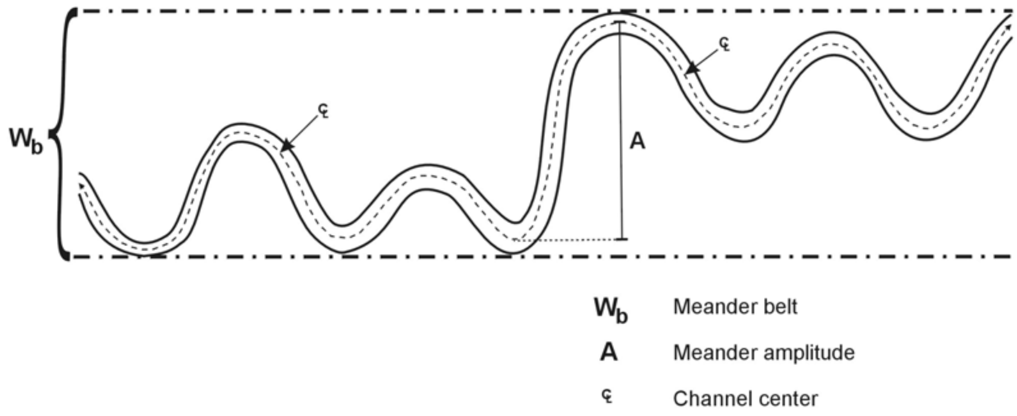


***Figure 2.3*:** Example of one specific meander defining the meander belt width for a reach.

2.5 Adjustments of Meander Form and the Meander Belt Width

With the exception of watercourses that have incised into metamorphic or igneous bedrock, a meander pattern seldom remains static through time. The configuration of individual meander bends, and of meandering reaches, often change during the processes of meander evolution and migration and in response to spatial and temporal changes in the factors that influence channel patterns (e.g., Burke, 1984, Klein, 1985). The rate and type of meander/planform changes that can occur are a function of floodplain/valley wall erodibility. If a controlling factor such as flow regime is altered, then the subsequent planform adjustments are a function of the type of hydrologic change (e.g., frequency, magnitude, volume, duration), the time interval during which the change has occurred (e.g., years, weeks), and the ability of the channel to absorb this change.

Most often, adjustments of single meander bends are a function of migration processes or of local influences in, for example, bank resistance (Hickin, 1974). The process of migration does not occur simultaneously along the entire length of a channel but, rather, occurs at discrete locations at any one time, leading to the alteration of individual meanders (Burke, 1984; Hagerty, 1984; Chang, 1992). Changes in the configuration of a single bend may include rotation, elongation, and a shift in meander axis (see Hooke (1984) for a summary of meander bend adjustments). Although the rate of meander adjustment and migration will vary along a meander due to characteristics of its local setting (e.g., vegetation, boundary materials, bank height, valley slope, discharge; Hickin and Nanson, 1975), it tends to be at a maximum just downstream of the bend apex.

Through a review of a sequence of historic air photos, and through an examination of detailed topographic mapping, it becomes evident that some watercourses experience substantial changes in planform configuration and in position on the floodplain. Change in configuration is most often a response to a substantial alteration in the hydrologic regime that is conveyed through a watercourse. Alteration of the hydrologic regime can occur in response to long-term climate change and water supply or may be induced by land use change. It follows that the meander belt of many watercourses has decreased significantly since deglaciation.

All channels are in a constant state of adjustment with respect to their controlling and modifying factors. While some of these adjustments are local, others affect longer sections of channel and may even affect the entire drainage network. The time required for a channel to adjust to any change in controlling or modifying influence is dependent on the extent of the change, the ability of the channel to absorb that change, and the erodibility of floodplain materials. Thus, at any one point in time, it is possible that the observed planform configuration is in a state of adjustment and therefore does not represent the equilibrium form that it has the potential to attain. With this reasoning, it is possible that the floodplain area that a watercourse occupies today does not represent the potential or ideal area that the watercourse will attain when it has achieved its equilibrium form at some point in the future. Further, even when a meandering channel has attained an equilibrium configuration, the position of the watercourse within the meander belt is expected to change. The position of the meander belt for a watercourse that has an equilibrium form may gradually shift across the floodplain, depending on the erodibility of the floodplain/valley materials. In other words, a stable channel is still expected to migrate within its belt width. This dynamic nature is an integral part of how streams work, dissipate energy and convey sediment.

Recent historic changes (1954-1996) along Highland Creek in Scarborough provide an example of the type of planform changes and migration that have been described in this section **(Figure 2.4)**. During the time period covered by a sequence of air photos, the drainage basin of Highland Creek has become increasingly urbanized which has affected the hydrologic regime of the creek (i.e., by increasing peak flows and flow volume). The creek has responded to this change by adjusting the configuration of individual bends, and shifting the position of some meanders in the downstream direction, thereby changing planform sinuosity. In **Figure 2.4**, Highland Creek is sometimes in contact with a valley wall. The valley wall consists of easily erodible materials (i.e., modern alluvium, sandy silt).

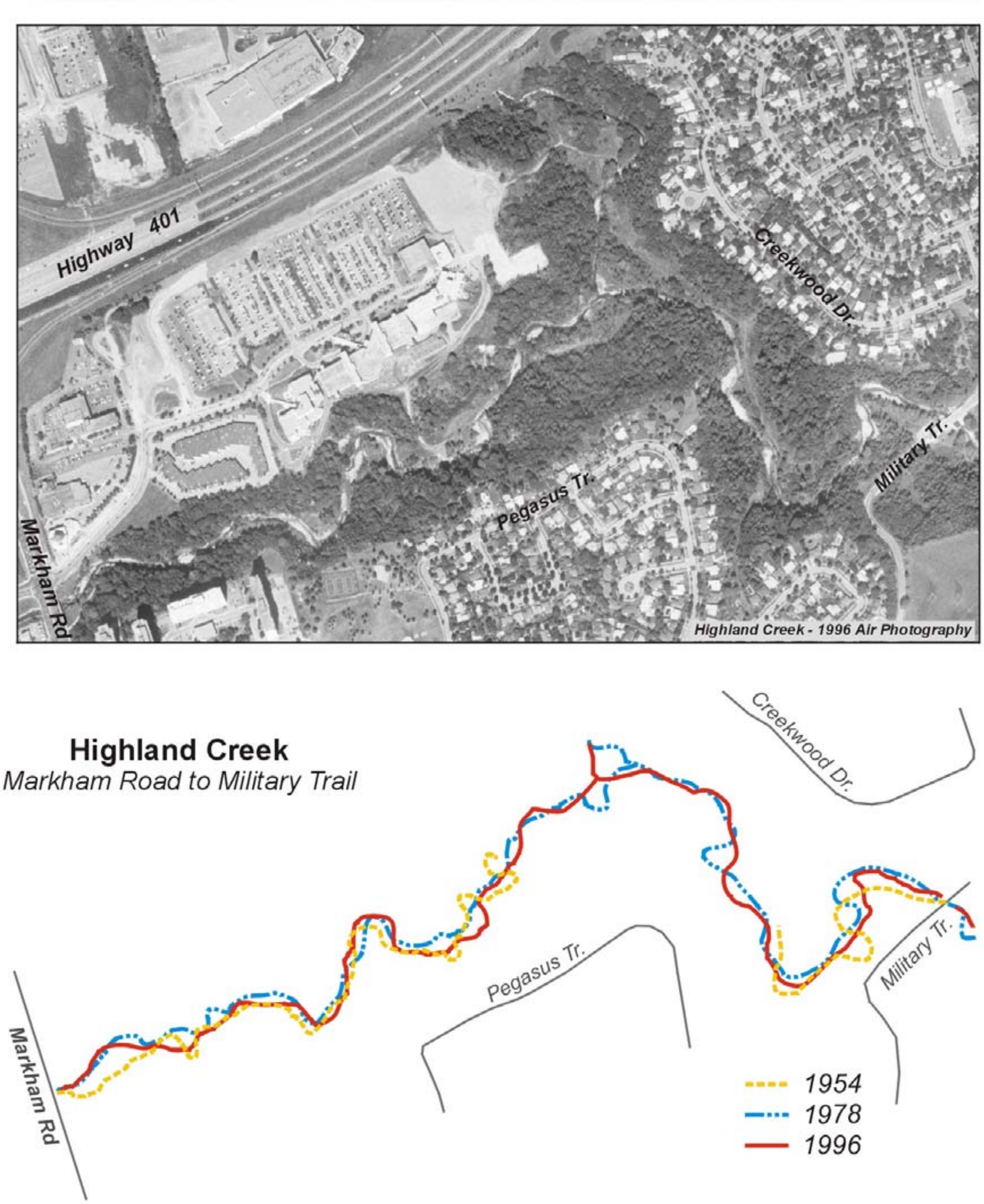


Figure 2.4: Extensive urbanization of Highland Creek's watershed has caused numerous adjustments in planform configuration since 1954.

2.6 Meander Belt in a Reach Perspective

Reaches are lengths of channel (typically 200 m – 2 km for S. Ontario watercourses) that display similarity with respect to valley/floodplain setting (relation between valley wall and channel, slope), channel form (e.g., planform, cross-section, bed morphology), and function. In addition, the controlling influences of channel form and function (e.g., water and sediment discharge, floodplain materials, and vegetation) should be nearly constant within the reach. It is at the reach scale where the setting, modifying and controlling influences of channel form interact to develop a relatively stable configuration that conveys water and sediment efficiently downstream while minimizing energy expenditure.

Due to spatial variability in the modifying and controlling influences of channel form, two reaches situated immediately up/downstream of each other could show a marked difference in planform **(Figure 2.5).** Further, although it is usually expected that the meander belt of a watercourse increases in width in the downstream direction since it is a function of discharge, this does not always occur. Local modifying influences (e.g., geology, floodplain vegetation) can cause the meander belt to vary in width within a drainage network.

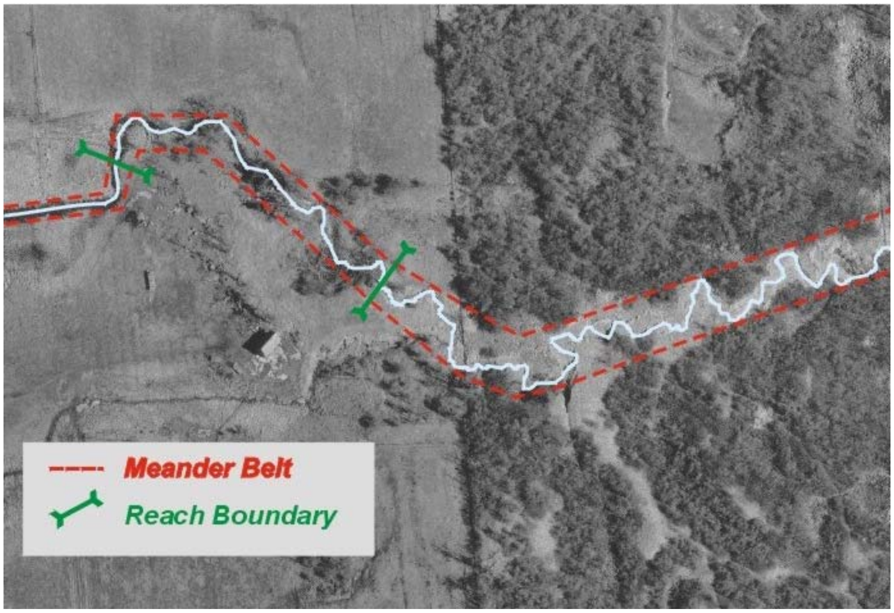


Figure 2.5: Illustration of how the meander belt will vary along a watercourse due to natural spatial variability (e.g., hydrology, floodplain vegetation or materials).

Every watercourse has a potential meander belt width given the general controls and modifying influences on its planform. The extent to which this width is realized on its floodplain, however, at the reach scale, is affected by the relation between the watercourse and its valley. When a watercourse is situated within a valley and contacts a wall on both sides of the meander belt (i.e., confined watercourse), then the bottom width of the valley is considered to be smaller than the meander belt. Thus, if the valley walls did not constrain the position of the watercourse, the area that the channel would occupy would be wider than the existing bottom valley width. If the valley wall consists of relatively erodible materials then, over time, the watercourse may cause sufficient erosion of the walls to increase the width of the valley floor, thereby enabling the channel to occupy its potential belt width. When a meandering watercourse contacts a valley wall on only one side of the meander belt (i.e., partial confinement), then it is assumed that the valley wall restricts the lateral migration of the belt and that it causes the belt to be somewhat compressed. It is possible, however, that the watercourse may have compensated for the presence of the one valley wall and that the width of the belt that is observed adjacent to the wall represents the potential belt width.

Although the meander belt defines the lateral extent of floodplain occupation by a meandering watercourse, it is not necessary for many meanders in the meander sequence to be at the limit of the meander belt. Thus, at a local scale, the meander belt for a few meander bends may be smaller than it is for the reach **(Figure 2.3).** This does not, however, suggest that the meander belt as defined for the reach is an inappropriate measure of meander floodplain occupation. Given that all controls and modifying influences of the watercourse are similar at the reach scale, it is expected that all meanders within the reach could respond in a similar way and occupy a similar position in the floodplain. Within the meander belt, it is expected that all of the natural meander evolution and migration processes occur.

Chapter 3

General Methods and Preparatory Work

3.1 Introduction

Through a review of the background information presented in **Chapter 2**, it becomes apparent that the width of the meander belt for any particular watercourse is variable and dependent on numerous factors. Although there is general agreement with respect to the definition of the meander belt among researchers in the scientific literature (i.e., lateral extent of floodplain occupation by a meandering watercourse), there is variation with respect to the methods used to quantify the belt width. This variation is essentially due to the different questions being asked by the researcher and to the variation in setting and watercourse history (e.g., evidence of active migration). The variation is also a function of the length of channel that formed the focus of the study. From the published literature, it becomes clear that the definition of a meander belt must consider the purpose for which it is to be defined. Although the methods would be similar, and would consider the general principles of meander form, migration and evolution, the accuracy of the quantified belt width that is required for a particular application can vary from other applications.

The objective of this chapter is to enable the practitioner to identify the appropriate belt width delineation procedure that satisfies the intended purpose of the work and to guide the practitioner through several key concepts and preparations that are common to all of the procedures.

3.2 Selection of Delineation Procedure

The scientific literature vary with respect to the methods that they use to quantify a meander belt, primarily due to differing study objectives and observed spatial variability in channel form within the study areas. Just as the purpose of defining the meander belt in scientific work varies (e.g., as the primary focus of a study or as a general descriptor for a study in which the primary focus is something else), so does the need to define a meander belt by a practitioner. Depending on the purpose of meander belt delineation, the amount of acceptable error associated with a measure of the belt width will vary. Recognizing that unnecessary levels of accuracy correspond to unnecessary cost expenditures, different procedures have been developed that consider both the objective and associated required level of accuracy. Regardless of this consideration, the amount of work that is required to define a meander belt is also a function of study area complexity.

To aid the practitioner in determining which belt width delineation procedure is most appropriate for the intended application, a brief summary is provided for each type of application that is identified below.

Procedure 1: General identification of meander belt (Chapter 4)

In some applications, such as at the subwatershed planning level, identification of a meander belt is intended mainly to show the location of the river corridor in the context of other landscape features (e.g., linkage between natural features in the landscape such as between woodlots and watercourse). Most often, the study area for this type of application is large and may include the entire subwatershed. In this type of application, the relative position and widths of the meander belt are of concern but precise values are not.

Procedures 2 - 4: Accurate quantification I (Chapter 5)

In some applications, the meander belt is to be defined for an existing watercourse or for a proposed watercourse relocation. **The hydrologic regime of the subject watercourse is not expected to be altered** in this type of application. If development occurs near the subject reach, then any excess runoff from the development area would not be received by the subject reach but would, instead, be discharged into the channel at some point downstream of the proposed development or into another watercourse. Accurate delineation and quantification of the meander belt is required for this type of application since it will affect planning of the site and corridor. When the area around the study area has already been developed, or is not intended for development in the near future, the belt width may need to be known for other purposes related to private property or to channel restoration

The requirement for accurate meander belt delineation and quantification is most often associated with proposed development areas to aid in the definition of development limits and/or to define a corridor for channel relocation. In both of these applications, the belt width delineation is a necessary first step in creating detailed development plans for the area of interest. ***Procedures 3 and 4*** are intended to define the meander belt as accurately and reliably as possible for the study area reach **when the hydrology of the watercourse is expected to be altered** as a result of the proposed development (e.g., receive runoff or storm water discharge from the development area).. Typically, channel length tends to range from a hundred meters to several kilometres in this type of application.

Procedure 5: Accurate quantification II - Empirical Approach (Chapter 5)

In many circumstances, an accurate delineation of the meander belt is required for a watercourse that has been altered. When the watercourse has been altered, it is necessary to examine the natural unaltered configuration of surrogate reaches (i.e., downstream, upstream, adjacent watercourse) to identify what the natural pattern may be for the study reach. In very few situations, a surrogate reach is not available and, hence, delineation of the meander belt for the study reach must rely on an alternative method. For this reason, an empirical relation has been developed that is intended to provide an estimate of the natural meander belt for altered watercourses for which no alternative method of belt width determination is available.

More detailed information regarding the appropriate use of the procedures are provided in the introductory paragraphs of each procedure **(Chapters 4 – 5)**. It is important to recognize that application of an inappropriate procedure for the sake of cost or time savings can lead to significant problems in the future especially when the belt width is inaccurately defined. Problems may also arise during the regulatory review phase and/or in consultation with clients.

3.3 Materials and Methods

The background materials presented in **Chapter 2** and in **Appendix B** reveal that the planform configuration of a watercourse, and hence the meander belt width, is a function of numerous factors. It should also have become evident that watercourses are in a constant state of adjustment and that as a response to spatial and temporal variability in controlling or modifying influences, the configuration of individual meander bends and of meander sequences change. To properly determine the meander belt for a given watercourse, it would be necessary to conduct a comprehensive investigation wherein each controlling and modifying influence of the planform was evaluated and the channel response to a change in these influences was determined. Some of the required information for such an investigation is not readily available or would require a significant amount of effort to obtain. Further, the scientific research that links the implications of changing one or more of the controls/modifiers of planform change on the meander belt is sparse within the literature. Even if detailed studies and modelling was completed, variability in setting and in the type of applications for which the meander belt is quantified would likely not be transferable to other projects.

To simplify the task of meander belt delineation, it is possible to rely on some surrogate means of estimating the general influence of controlling and modifying factors on the planform configuration of a watercourse. For example, insight into the resistance exerted by geology, floodplain materials, and riparian vegetation on meander bend development and migration can be inferred from measurements made from an historic sequence of air photographs. Thus, each of the procedures that have been outlined in this document draws upon information that is available from topographic and geologic mapping and from aerial photographs. The required mapping scale varies with amount of acceptable error that is associated with each type of application. Some additional information that may be required for some of the procedures will be identified within the procedures themselves. Delineation of the meander belt constitutes primarily a mapping exercise. It is possible that by relying on surrogate information and by simplifying the method of meander belt determination that an over- or under-estimate of the belt width may occur.

In fluvial geomorphological investigations, characteristics and processes of a watercourse are often analyzed and examined at a reach scale. At this scale, the controlling and modifying influences of channel form tend to be similar, leading to the assumption that channel form, function, and process within the reach are also similar. Thus, although characteristics of the setting and their interaction with the watercourse may not have been explicitly identified, their role is recognized. Delineation of a watercourse or segment of a watercourse into reaches is the first step in meander belt determination exercise.

In **Section 2.3** a sequence of meanders was described as being either simple or compound **(Figure 2.1)**. It is generally assumed that all meanders will migrate in the downstream direction. This direction is often dictated by valley trends since the channel will tend to occupy the lowest elevation of a floodplain. When the planform configuration is compound, the direction of meander migration becomes more difficult to determine. Most often, the meanders are likely to migrate in a meander pattern that follows the compound structure **(Figure 3.1).** Thus, before a meander belt can be determined, it is important to identify the valley trend and axis of the meander belt.

Since the processes of reach delineation and identification of valley trends and meander belt axes are common to all of the procedures that are described in this document, their methods are presented here to avoid redundancy and allow for easy common reference.

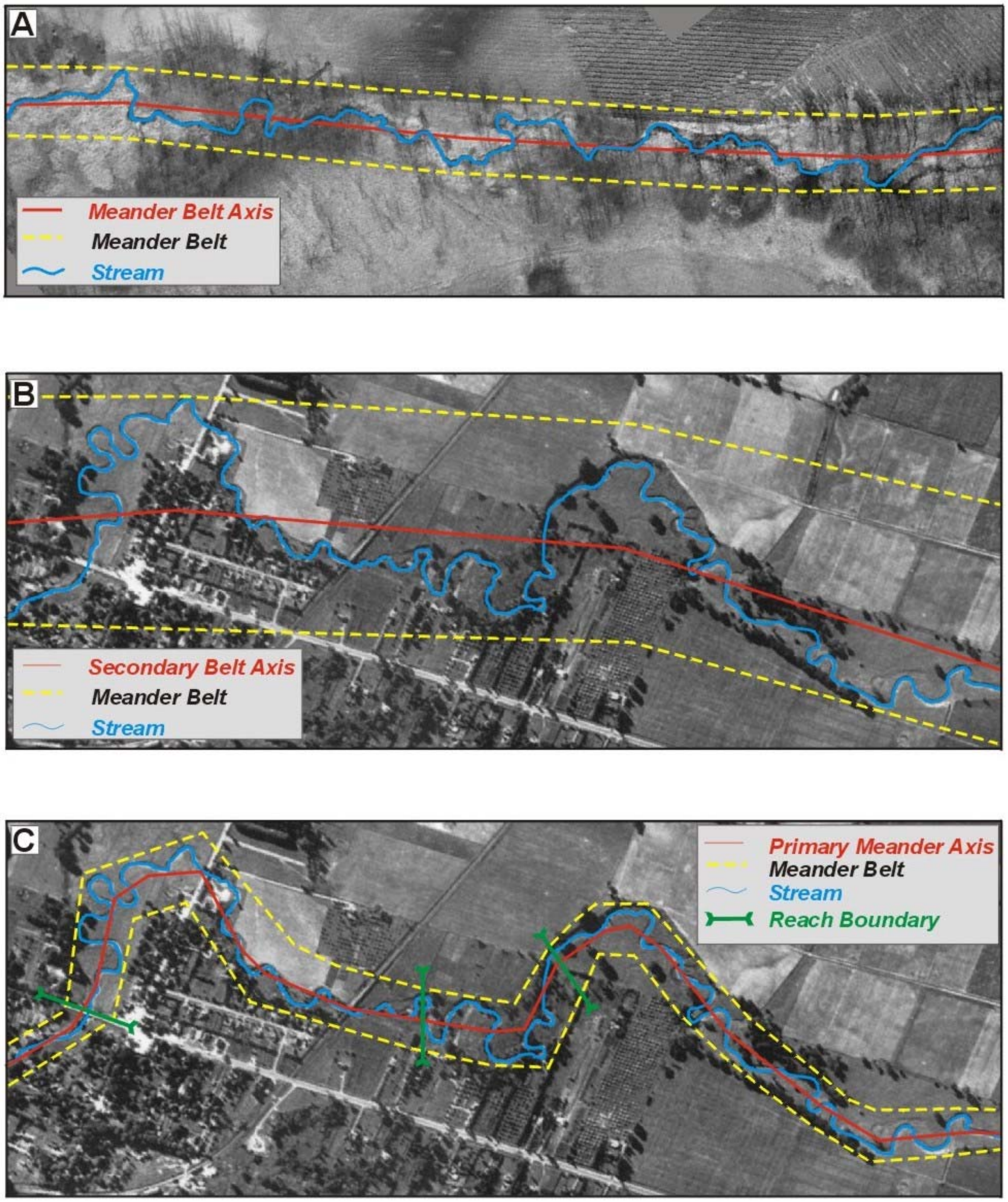


Figure 3.1: The meander belt axis is a conceptual line that shows the general down-valley orientation of a meandering planform. (a) typical meander belt axis (b) compound meander with a nearly linear belt axis (c) belt axis following compound meander trend.

3.4 Step 1: Reach Delineation

In the scientific literature, reaches are defined as lengths of channel that display similar physical characteristics (e.g., sinuosity, simple, compound, regular or irregular meander patterns) and have a setting that remains nearly constant along its length (e.g., geology, valley setting, land use, and land cover) (e.g., Rosgen, 1994; Montgomery and Buffington, 1997). Thus, in a reach, the controlling and modifying influences of channel form are similar. From this premise, it follows that characteristics of channel form, function and processes (e.g., migration) within the reach are also similar and will differ from adjoining reaches (e.g., channel tends to be wide and shallow in forested areas and narrow and deep in grassy areas (e.g., Murgatroyd and Ternan, 1983; Trimble, 1997)). With this assumption it is possible to identify a meander belt for a length of channel since, within the reach, all processes are expected to occur at similar rates and the channel is expected to respond similarly to any change in controlling variables (e.g., hydrologic regime). Thus, given that the planform configuration and channel processes vary spatially in the downstream direction, the meander belt is best defined for each individual reach along a watercourse than for an entire river. Further, when a meander belt needs to be defined for only a portion of a reach, care must be taken to apply the belt width delineation procedure to the entire reach since the processes that are operative at the broader reach scale are applicable to the local site.

Reach length will vary along a drainage network, but, for the watercourses that are situated within the Greater Toronto Area, is typically between 200 m and ~ 2 km. For the purpose of the meander belt delineation procedures, influences on planform and meander processes that occur at the reach scale are of interest.

To identify reaches along a watercourse or drainage network, the following materials are required.

- Topographic mapping of drainage network in study area (***Procedure 1***) or extending upstream and downstream of the study area (***Procedures 2 – 4***);
- Geologic mapping of study area;
- Recent aerial photography of study area.

Given the definition of a reach, it is necessary to identify lengths of channel that display similar physical characteristics and whose setting remains relatively unchanged along the length of the channel. When any of the following variables change along a watercourse, then this tends to demarcate the position of a new reach boundary:

- Hydrology (e.g., addition of a tributary)
- Sinuosity
- Valley setting (e.g., confined, partially confined, unconfined)
- Gradient (e.g., steep, gradual)
- Geology **(*only for Procedures 2 - 4*)**

3.5 Step 2: Meander Belt Axis

The meander axis is a term used to describe the general down-valley orientation of the meander pattern. The meander belt is essentially centered around the meander axis. Although identification of the meander axis can be relatively straightforward for simple meander patterns, when the meander pattern is compound, then identification of the meander axis is more complex.

The meander belt follows the general down-valley trend of the planform pattern which is more appropriately referred to as the meander belt axis **(Figure 3.1)**. While the meander belt axis can be readily identified for a simple meander pattern, when the meander pattern is compound, it becomes more complex since the compound meander is characterized by two different scales of meandering form **(Figure 3.1b and c)**.

3.5.1 Simple Meander Patterns

In simple meander patterns, the belt axis follows the general down-valley trend of the planform and is most often linear or quasi-linear **(Figure 3.1a)**. The meander axis should be defined for individual reaches and should link to the meander axis of adjoining reaches **(Figure 3.2)**.

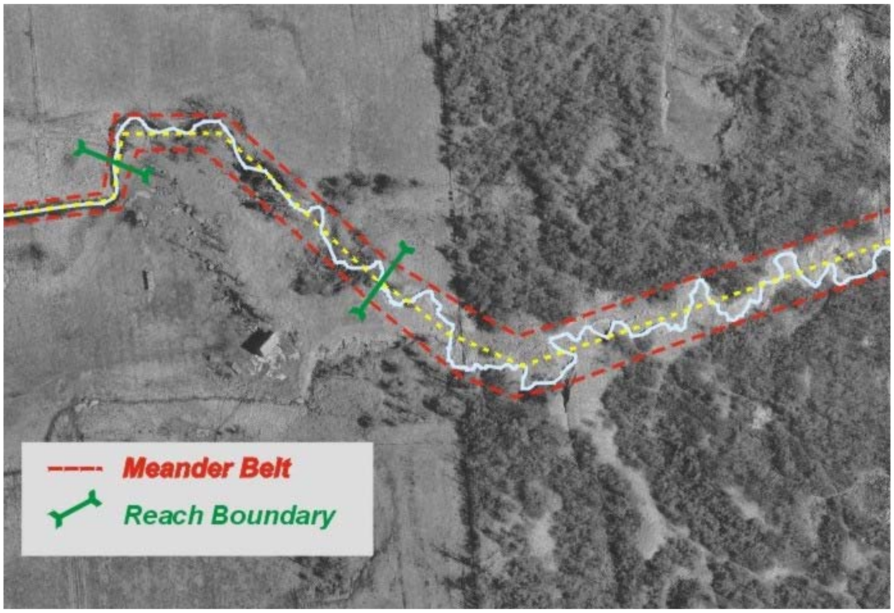


Figure 3.2: The meander belt axis should be defined for each reach and then joined to the adjacent reaches to form one continuous line.

3.5.2 Compound Meander Patterns

In compound meanders, two meandering patterns are superimposed **(See Section 2.3 and Figure 2.1)**. Carson and Lapointe (1983) suggest that the meander belt axis for compound meanders should follow the primary belt axis **(Figure 3.1c)**. Given that the meanders along the primary belt axis are superimposed on a secondary axis, it is conceivable that primary meander pattern would gradually shift downstream, albeit in all likelihood within the primary belt width.

Estimation of meander position on the floodplain, or indeed an estimation of channel dimensions at some point in the future, is restricted by limited knowledge regarding future climate changes and precipitation patterns which could conceivably cause surface discharge to increase or decrease significantly enough to cause a morphologic channel response. Other future changes in the controlling and modifying influences of channel pattern can not be foreseen and only estimated at best. The position of individual meander bends in a compound meander pattern are expected to shift in position mainly along the primary meander belt axis **(Figure 3.1c)**, evident through a review of historical aerial photographs. Thus, applying the meander belt to the primary belt axis is considered to be an appropriate strategy, especially given that the secondary pattern may be a glacial relic or controlled by extreme (> regional event) floods.

3.5.3 Incised Watercourses

Although the dominant process of incised watercourses is degradation (i.e., lowering of the channel bed) and head cutting (i.e., flattening of the profile to remove any large drops in elevation), their planform has a slight sinuosity. This sinuosity sometimes reflects local variance in the erodibility of floodplain materials. The incised condition of watercourses in most settings that are under the jurisdiction of the TRCA is temporary and, through time is expected to resemble the meander configuration of the downstream reach. Nevertheless, for incised watercourses, the meander belt axis should follow the trend of the incision pattern and link the axis of the upstream and downstream reaches.

3.6 Step 3: Meander Belt Delineation

When the meander belt axis has been identified, delineation of the meander belt boundaries can begin. In essence, the limits of the meander belt are defined by parallel lines drawn tangential to the outside meanders of a planform for each reach in the study area. While this is a relatively simple procedure, it is confounded by the general valley setting of the watercourse. There are four types of valley settings for watercourses, including:

Unconfined – where there are no limits or controls on the spatial occupation of the floodplain by a watercourse;

Partially confined – where the meander bends are adjacent to only one valley wall with the reach. The watercourse is restricted in migration and floodplain occupation along one side of the valley;

Confined – where meander bends are adjacent to both valley walls within the reach; the watercourse may be restricted from occupying its potential meander belt by the valley walls (see **Chapter 2.5**);

Incised – where the watercourse is actively incising into the floodplain or valley.

When an accurate delineation of the meander belt is required **(*Procedures 2 - 4*)**, then it is necessary to examine the historic position and configuration of the planform for the study reach. This would require an overlay of the reach(es) based on historic air photos.

3.6.1 Unconfined Meander

In the case where the spatial position of a watercourse is not influenced by valley walls or by a landscape feature, the meander belt is defined as recommended by Leopold and Wolman (1960). In this method, tangential lines are drawn along the outside bends of the laterally extreme meanders within the reach, but follow the general valley trend **(Figure 3.3).** The distance between the two lines is measured and used to represent the width of the meander belt. For ***Procedures 2 - 4***, the belt width boundaries are drawn to the outside bends of the overlay, thereby including the planform of all three period of air photo coverage **(Figure 3.4).**

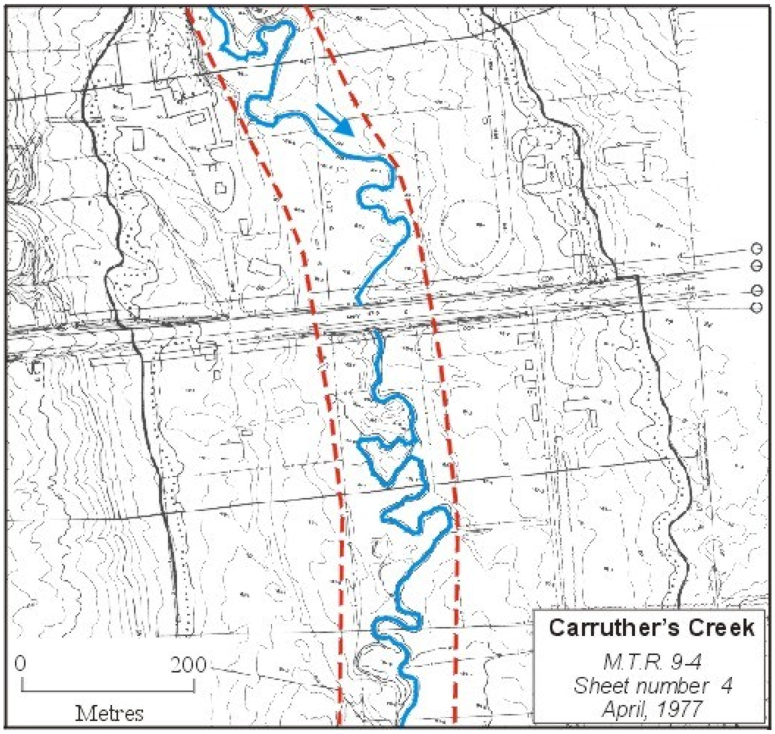


Figure 3.3: Limits of the meander belt are defined as the area that is between tangential lines to the outside meanders of laterally extreme meanders on the floodplain.

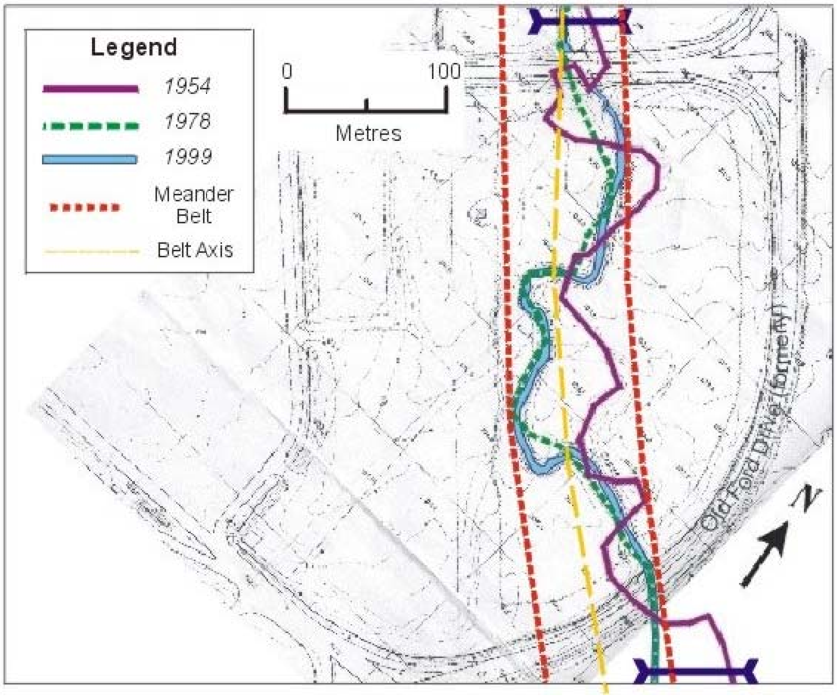


Figure 3.4: Accounting historic planform information, the meander belt was defined for an unconfined section of Joshua Creek in Oakville.

3.6.2 Partially Confined Meanders

In the case where the spatial position of a watercourse is influenced in one direction by a valley wall, then meander belt delineation must take into account the influence of the valley wall. The meander belt should first be defined as described in **section 3.5 (Figure 3.3)** as consisting of tangential lines drawn to the outermost meander bends of the reach and following the general valley trend. Then, on the side where the watercourse is adjacent to the valley wall, modification of the boundary occurs.

Since the valley wall is considered to be a constraint to meander migration, it serves as the meander belt boundary. The top of the valley would be considered to be the limit of the meander belt. Because most valley walls are sloped and not nearly vertical, it is important to define the position of the meander belt more reasonably. Specifically, the meander belt should be adjusted to account for the irregularity of the valley wall such that the belt boundary can be situated both in the valley and at some point along the valley wall. In ***Procedure 2***, the meander belt position takes into account the historic meander patterns. It must be noted that **this definition of the meander belt does not consider any slope**

stability issues, and that some additional setback would be required to address the geotechnical hazards.

Figure 3.5 shows an example of the meander belt defined for a partially confined watercourse. **Figure 3.7** shows another example but this time for a confined meander, which is similar in principle to the partially confined meander belt, with historic planform information (i.e., for ***Procedures 2 – 4***). The meander belt width would disregard any irregularities such as scalloped valley wall, as the channel would be expected, over time to erode these features.

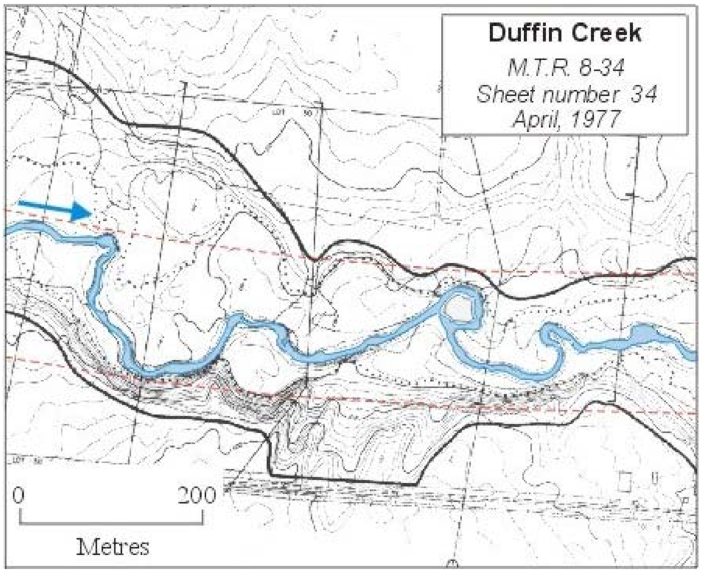


Figure 3.5: For a partially confined meandering watercourse, limits of the meander belt are guided by the valley wall and by the laterally extreme position of meanders where the channel is unconfined.

3.6.3 Confined Meanders

In the case where a reach is confined by valley walls along both sides of the planform, the meander belt is first defined by drawing lines tangential to the outside meander bends of the planform, following the valley trend. Since the valley walls essentially act as the boundary of the meander belt, the boundary should coincide with the top of the wall. Because most valley walls are sloped and not nearly vertical, it is appropriate to adjust the boundaries to a more reasonable position. The adjustment accounts for the irregularity in the valley walls (e.g., resistant outcrops) and the natural tendency of watercourse occupation within the valley. It must be noted that **this definition of the meander belt does not consider any slope stability issues**. It is recognized that when a channel is confined in a valley that the width of the valley bottom is smaller than the natural meander belt width that the watercourse would attain if it were in an unconfined setting.

Adjustment of the meander belt boundaries are shown in **Figures 3.6** and **3.7**. Historic information was used in **Figure 3.7** to define the meander belt. Given the natural variability in valley width, it follows that the meander belt as defined by the valley walls will also vary in width. To quantify the belt width, it is recommended that the maximum width be used to represent the meander belt.

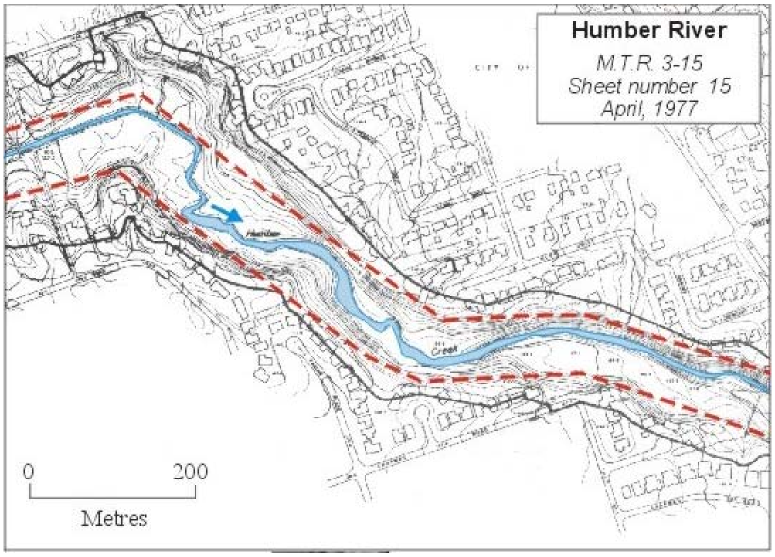


Figure 3.6: When a meandering watercourse is confined within a valley, then the meander belt boundary is placed at an average distance between the top and bottom of the valley walls along both sides of the watercourse.

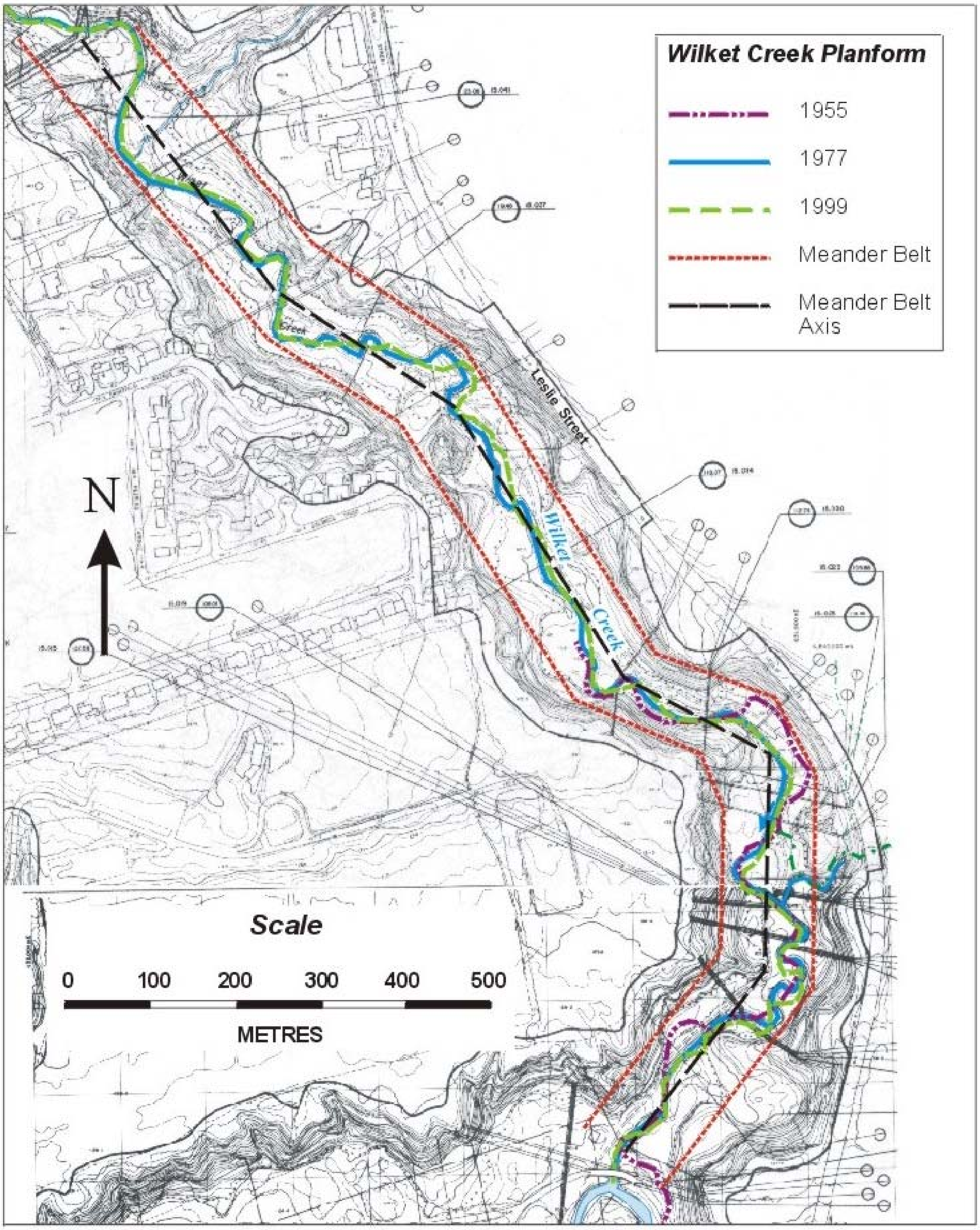


Figure 3.7: Historic planform information and floodline mapping was used to define the meander belt for Wilket Creek which is confined in a valley setting.

3.6.4 Incised Meanders

In the case where a reach has actively incised into its floodplain, as evident by the contour pattern on topographic mapping, the meander belt could be defined as the area between laterally extreme meander bends in the planform pattern, similar to the process described in **3.6.2**. This method would not, however, take into consideration future evolution and development of the incised watercourse. When a watercourse is incised (e.g., due to a large knickpoint in its profile) then this condition is considered to be temporary. Over time, as the watercourse continues to incise, it will also begin to erode the erodible valley walls and create a floodplain. Given the relative erodibility of the settings in which most of the watercourses that are under the jurisdiction of the TRCA are situated, consideration of the potential future belt width is imperative.

Since the intent of the belt width delineation procedure is to define an area that would contain watercourse processes so that the risk to life and property would be minimized. Insight into the potential width of the future meander belt can be gained by examining the configuration of the downstream or upstream reaches, as long as these reaches are in similar geologic settings. The belt width of the downstream or upstream reach would be measured and centred over the meander axis of the incised watercourse. This belt axis would follow the general down-valley trend of the incised reach **(Figure 3.8)**.

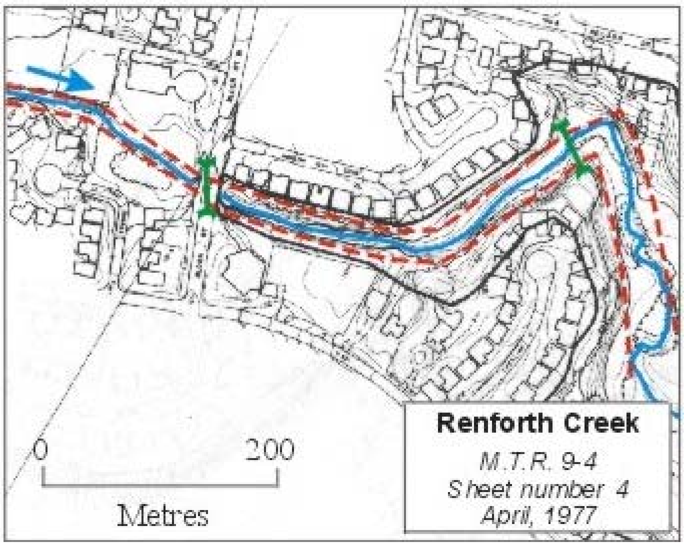


Figure 3.8: The meander belt that has incised into its floodplain is defined as the distance between lines drawn tangentially to outside meander bends of the planform configuration.

3.7 Summary

Before any of the meander belt delineation procedures can be applied to any particular application, the study area should be divided into reaches and a meander axis should be defined for the watercourse. Once the methods outlined in **Sections 3.4** and **3.5** have been applied to the study area, application of the procedures can begin.

Chapter 4

Procedure 1: Subwatershed or General Planning Studies

4.1 Introduction

As part of a general planning exercise, such as subwatershed studies, it is sometimes of interest to identify the extent of the river corridor. This is best accomplished through identifying the meander belt. Most often, the purpose of this exercise is to illustrate the spatial position of the meander belt in relation to other features and to gain a general appreciation of the area which would be designated as a meander corridor. The meander belt would be identified for channel reaches throughout the subwatershed. Given the large area and the general nature of the application, only a general notion of the meander belt's position within the floodplain would be identified. Thus, ***Procedure 1*** for delineating a meander belt does not take into account the possibility that the watercourse has not yet developed a quasi-equilibrium form or future migration trends. For this reason, although the meander belt defined for the general subwatershed or planning study would provide an estimate of its extent, it would be an underestimate of the actual belt width. Refinement of the belt width boundaries is intended to occur during the more detailed work conducted at the secondary planning stage of a subwatershed study and for proposed development areas (***Procedures 2 - 4***).

4.2 Materials

The materials that are required to identify the meander belt for a watercourse at the subwatershed or general planning scale consist essentially of topographic mapping. The accuracy with which the meander belt can be defined will depend on the scale of the mapping. The smaller the scale (e.g., 1:50,000), the less reliable the width of the meander belt will be for any type of planning purposes. Unless the subwatershed is a very large area, it is recommended that **topographic mapping at a scale of 1:10,000** or **1:20,000** be used to define the meander belt to achieve a reasonable accuracy in belt width delineation.

4.3 Assumption and Limitation of the Procedure

Even though delineation of the meander belt is intended to be for a general planning purpose, it is important that the position and relative width of the meander belt be portrayed as accurately as possible. Thus, it is recommended that care be taken while completing the general meander belt delineation work as it most likely will form the basis for further work, and is expected to be used to draw general inferences for subwatershed planning in proximity to the watercourse. Regardless of the care that is taken in applying this procedure, there are assumptions and limitations associated with its application:

Assumptions:

- Existing meander configuration represents equilibrium condition between meander pattern and the driving forces of meander form;
- Meander belt is not actively shifting across the floodplain.

Limitations:

- Accuracy of meander belt width position is dependent on scale of mapping;
- Meander belt does not take into account future changes in meander configuration, especially for previously straightened sections of channel;
- Meander belt does not take into account future geotechnical slope stability adjustments;
- Width of meander belt is an estimate and not suitable for detailed planning or analytical purposes.

4.4 Background Preparation

Before applying the meander belt delineation procedure that is described in ***Procedure 1***, it is necessary to define the study area, and to identify reaches along the watercourse as described in **Section 3.4**. Identification of the meander axis as described in **Section 3.5** is not considered to be necessary for ***Procedure 1***.

4.5 Delineating the Meander Belt

For ***Procedure 1***, delineation of a meander belt is a relatively simple undertaking. Since the purpose of identifying the meander belt is to indicate spatial position and relative belt width on mapping, the meander belt is essentially defined as recommended by Leopold and Wolman (1960), Carlston (1965), Chang and Toebes (1970) and Annable (1996b). The methods have been described in detail in **Chapter 3.6**. Due to the generalized nature of ***Procedure 1***, rigour in completing the delineation is not required. Specifically, although it is not considered necessary to identify the meander belt axis, the general valley trend which is often similar to the belt axis is used as a visual guide for the purpose of delineating the meander belt. Further, historic information that can provide valuable insight into the meander belt, is not considered necessary for ***Procedure 1***. **Figure 4.1** illustrates how the methods described in **Section 3.6** have been applied to a large study area such as that which is typical of subwatershed studies to gain a general indication of the meander belt location and width.

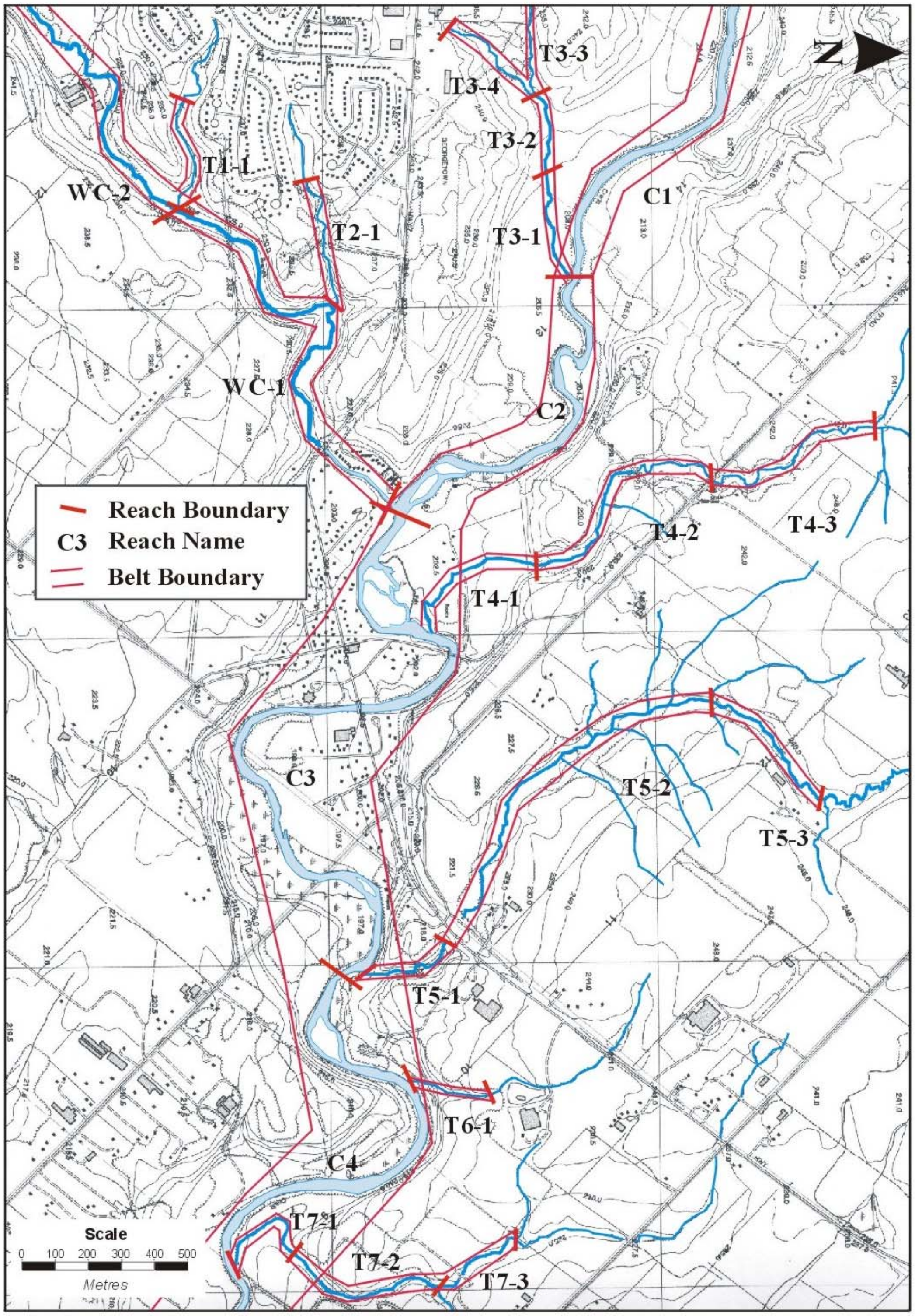


Figure 4.1: This figure illustrates the general application of belt width delineation **Procedure 1** for watercourses located in Georgetown, Ontario. The watercourses in the study area were divided into reaches (see **Section 3.4**) and meander belt boundaries were then identified based on the principles that were presented in **Section 3.6**.

4.6 Summary

Delineation of a meander belt for the purpose of representing the general area that a watercourse occupies within its study area is a relatively simple process. The watercourse is divided into reaches for which the meander belt is defined in a manner that is suitable for its general position on the floodplain or relation to the valley through which the channel flows. The methods described in this procedure rely only on the use of topographic mapping. Since the detail of the procedure is simple and the scale of the mapping is relatively small, refinement of the meander belt for more specific purposes should follow the methods described in other procedures presented in this document.

Chapter 5

Accurate Meander Belt Delineation

5.1 Introduction

Accurate delineation of a meander belt is important for many planning purposes that entail proposed works or development in proximity to a watercourse, realignment of a channel, and/or determining the appropriate span of watercourse crossing structures. In the case where realignment is proposed, quantification of the belt width is an important element in completing the channel design. Each of these applications require the meander belt width to be known to a reasonable degree of accuracy to enable planning of the surrounding land area to proceed.

During the planning process, delineation of the meander belt is intended to define the area in which all natural existing and future watercourse processes could occur, thereby minimizing future risk to private property and structures. To enable a future prediction of the meander belt for a given watercourse, it is necessary to consider the controlling and modifying influences of channel planform. When these influences remain relatively unaltered through time, then the configuration (i.e., cross-section, profile, planform) of watercourses attain a state of quasi-equilibrium. If, however, any of these influences are expected to change in the future, then it can reasonably be expected that the planform configuration will also be altered, thereby affecting the meander belt width. As discussed in **Chapter 2** and in **Appendix B,** the main controls of watercourse planform include hydrologic regime, erodibility of floodplain materials (i.e., surficial geology, riparian vegetation), and topography (i.e., slope).

The hydrologic regime of a watercourse consists of three distinct components: magnitude, frequency, and duration. The configuration (i.e., cross-section, profile, planform) of a watercourse in addition to its natural functions and processes are largely governed by its hydrologic regime. Most often the 'bankfull' discharge is considered to be the channel forming discharge, or the flow to which the channel form has adjusted. In other watercourses, the 'effective' discharge, the flow that transports the largest volume of sediment in a given hydrologic year, is considered to be the channel forming discharge. This being said, determining the effective discharge requires a long term record of flows and sediment transport data. When a quasi-equilibrium channel has developed, the bankfull and effective flows tend to be identical.

When the land use and/or cover of an area changes, the hydrologic cycle (i.e., the pathways through which water cycles from the atmosphere through the earth's surface and back to the atmosphere) may be affected, depending on the type of change that is proposed. If the hydrologic cycle is interrupted or altered, then a consequent alteration of the hydrologic regime of the receiving watercourse(s) invariably occurs. Given the dependence of channel form on hydrologic regime, the planform configuration and hence meander belt width would be directly affected. The type and extent of channel adjustments that occur in response to a change in hydrologic regime depends on the magnitude of the change, how quickly the change occurs, and the ability of the channel to absorb this change. Broadly, the channel response can be grouped into alterations in cross-sectional shape and area, bed and/or meander configuration.

Within the scientific literature, the response of watercourses to changes in hydrologic regime has been recorded. Booth (1990) found that the urbanization in headwater areas caused channel incision and enlargement of the headwater tributaries (note: no storm water management practices were used to mitigate the effect of urbanization on the hydrologic regime). Through observations of watercourses, it is evident that a positive correlation exists between meander belt width and discharge (i.e., belt width increases as discharge increases).

Management of the hydrologic regime has evolved significantly over the years. Since the 1980s, more extensive steps have been taken to reduce the impact of changing land use on the hydrologic cycle, and hence to the hydrologic regime of watercourses. The result was the development of storm water management (SWM) practices that address the issue of excess runoff that occurs as a consequence of an increase in the impermeable surface area. The focus of flooding and peak flow control measures resulted in an increase in the duration of the storm hydrograph. In addition, the frequency of small flood events increased as a direct result of the extensive impervious surfaces and the sewer systems.

Through increasing awareness of the impact of urbanization on receiving watercourses, SWM practices developed further with the intent of mitigating the impact of increasing flow volume and water quality concerns. The result has been a trend towards maximizing on-site infiltration to reduce runoff volume, matching post-pre peak flows, and reduction of flow durations above critical threshold values. Unless the volume increase of surface water runoff is minimal or negligible for the area where land use/cover is altered, then key elements of the hydrologic regime that affect the planform are altered. The specific elements that will cause a response in channel form will vary depending on the erodibility and composition of floodplain and substrate materials. When the frequency of flows that are equal to or greater than the channel forming discharge increases, then the rate of channel adjustments and migration will occur more rapidly.

When the hydrologic regime of a watercourse is anticipated to change, then this fact should be incorporated into the belt width delineation procedure such that the potential future floodplain occupation of the watercourse can be estimated. The effects of hydrologic regimes altered through SWM has not been well documented in the scientific and non-scientific literature. This lack of information is attributable to the fact that SWM is still a fairly recent development whose effects on watercourses are still being documented and are not yet fully understood. Given our current geomorphologic understanding with respect to hydrologic regime and channel form, some channel responses can be inferred while others have been documented. Nevertheless, for the purpose of delineating a meander belt, at this time (2001), it is necessary to develop a general procedure that considers whether or not the hydrologic regime of the watercourse is expected to change.

In addition to hydrologic regime, the controls of planform configuration are erodibility of floodplain materials and channel slope. Since the purpose of most planning activity is to alter land use or land cover, the vegetation that is adjacent to the watercourse does not tend to change, unless realignment of the channel is proposed. When realignment does occur, however, corresponding re-vegetation plans most often include species that naturally occur adjacent to the existing channel. In most situations, although land use/cover of an area surrounding a watercourse may change, the erodibility of the floodplain as a function of boundary materials will not. Similarly, the gradient of a watercourse is unlikely to be altered unless lowering of channel inverts is proposed for culverts. Since no change in either riparian vegetation or channel gradient are expected, only changes in hydrologic regime would induce an alteration in planform configuration.

For most applications, the study area is adjacent to only a small length of channel rather than the entire reach. Although the area of interest is small, it is part of the longer reach and therefore subject to all the influences and processes that are occurring in the reach. For this reason, quantification of the meander belt for the study area should be completed for the reach and rather than only for the length of channel that is adjacent to the study area. This will ensure that potential future processes have been considered.

In all possible applications for which the meander belt is to be identified and quantified with reasonable accuracy, the intent is to define a corridor that will contain all of the existing and expected future meander development and migration processes. For this reason, it is imperative to identify whether the hydrologic regime of the watercourse is expected to be altered since this fact affects how the belt width should be defined such that potential future risk of erosion and damage to private property and structure is minimized.

Each of the methods that have been developed in ***Procedures 2 - 5*** are intended to quantify the meander belt with reasonable accuracy. When the hydrologic regime is not expected to change, ***Procedure 2*** is appropriate. When the hydrologic regime is expected to change (i.e., frequency, duration and/or volume), then ***Procedures 3 – 5*** are appropriate. To identify which procedure is most applicable, several examples are provided below.

Procedure 2: Change in Hydrologic Regime IS NOT **Anticipated**

For the purpose of defining a meander belt, a change in hydrologic regime is not expected to occur in the following scenarios:

  - **Watercourse crossing structure**:
    - In conjunction with no other works;
    - In conjunction with other planning where proposed changes in land use/cover are not expected to cause an alteration of hydrologic regime to the watercourse for which the crossing is intended.
  - **When an alteration in land use/cover is proposed:**
    - Proposed land use/cover changes are minimal and would not be anticipated to cause an effect on the hydrologic cycle;
    - Surface runoff from proposed land use/cover is directed into a watercourse other than that for which the meander belt is to be quantified.

Procedures 2 - 5: Change in Hydrologic Regime IS **Anticipated**

For the purpose of defining a meander belt, a change in hydrologic regime occurs in the following scenarios:

- **Proposed land use/cover change adjacent to watercourse** which causes a change (i.e., increase) in volume of surface water that is conveyed to the watercourse and may also cause an increase in peak flows and flow duration, even when SWM practices are used.

- **Storm water flows from development are directed into a watercourse,** either adjacent to, or at a distance from the development area. Discharge from the development would affect peak flows and/or duration of flow events and flow volume of the receiving watercourse.

5.2 Materials

When delineating the meander belt for a study area, it is necessary to focus the analyses not only on the affected section of channel but also to extend the analyses for the entire reach(es) along which the study area occurs. When the existing channel within the study area has been previously altered, then it is necessary to extend the meander belt delineation work to an upstream or downstream reach that has not been previously altered. If the upstream or downstream reaches have also been altered, then it will be necessary to identify a surrogate reach or conduct other analyses. To enable the application of ***Procedures 2 - 5*** for the purpose of accurately defining the location and width of the meander belt, the **materials that are required for the study area and adjoining reaches include**:

- large scale topographic mapping (1:2,000, 1:1,000 or larger);
- detailed geology mapping;
- sequence of historical aerial photographs;
- aerial photograph of existing conditions;
- Two-year flow and drainage area for downstream limit of study area in the situation where the existing watercourse and adjoining reaches have been previously altered.

5.3 Assumptions and Limitations

The intent of ***Procedures 2 - 5*** is to define the meander belt of an existing watercourse as accurately as possible. Given that scientific knowledge and research pertaining to the meander belt width is limited, and that a thorough undertaking of meander belt width delineation would be a very costly and time consuming work, the procedures that are described in this document have several assumptions and limitations, no matter how carefully and precisely the methods are followed:

Assumptions:

- the meander migration and evolution processes that occur within the reach will continue to occur into the future;
- the meander belt, as defined in **Procedures 2 - 5**, encompasses the area in which all future meandering and migration tendencies of the watercourse are anticipated to occur.

Limitations:

- calculated meander migration rates are dependent on quality and time-span of historic air photo record;
- precise direction and sequence of meander evolution and migration direction cannot be easily predicted;
- meander belt does not take into account any consideration of geotechnical slope set-backs for valley walls (e.g., confined or partially confined setting);
- accuracy of meander belt is dependent on the care taken to complete the work described in this document
- there is some subjectivity in the meander belt delineation procedure although when it is defined by a practitioner who has a general appreciation of planform processes, the subjectivity decreases

5.4 Background Preparation

Before applying the meander belt delineation procedures that are described in this document, several preparatory steps need to be undertaken. Because it is assumed that the fluvial processes that occur within a reach are similar and can occur anywhere within the reach, the procedures described below should be applied to all reaches affected by the study area.

5.4.1 *Step 1: Reach Delineation*

The watercourse within the area of interest should be evaluated to determine whether one or more reaches occur. All subsequent analyses need to be completed for all affected reaches unless the reach and the adjoining reaches have been previously altered and the natural configuration is not evident in the floodplain. General guidelines for reach delineation were outlined in **Section 3.4**.

5.4.2 *Step 2: Meander Axis*

To enable an accurate quantification of the meander belt, it is important to identify the meander belt axis. The methods used to define the axis should follow the description given in **Section 3.5**.

5.4.3 *Step 3: Historic Analyses*

At any point in time, whether or not the configuration of a watercourse is truly in a state of quasi-equilibrium with the flows that are conveyed through it cannot always be discerned due to unknown alterations in hydrologic regime (e.g., long-term precipitation trends). To allow for the possibility that the configuration of an existing watercourse/reach may not be in quasi-equilibrium form, historic analyses of the reach should be completed. The intent of the analyses is to identify the type and rate of migration and meander development processes that have occurred during the available air photo record and the area that the watercourse has occupied. It can reasonably be expected that the historic channel processes will continue into the future and are therefore used in the meander belt delineation process to identify the area that the reach could occupy in the future. The air photos also enable human alterations of the channel form to be identified, some of which are not always readily discernible.

The historic analyses are best completed by creating an overlay of the reach(es) during different periods of time. It is recommended that the overlay draw upon at least three different historic air photos or historic mapping (e.g., floodline mapping) that extend from the earliest (i.e., 1930s, 1940s or 1950s) to most recent coverage (e.g., 1999 – 2001). The choice of a third photo (or map) should be based on photo scale; it is best if the scale is large (i.e., more detail on the photos, typically in the 1970s or 1980s).

The watercourse that is present on each of the air photos is traced and overlain onto a base map. This enables channel changes to be viewed in the context of their general setting. In the event that the study area reach(es) are obscured on the air photos by dense forest cover, every effort should be made to identify the configuration of the watercourse through the tree cover. If this task cannot be completed (e.g., in cases where watercourse is very narrow), then the historic analyses should be undertaken by relying only on the topographic mapping.

In addition to tracing the watercourse, if floodplain features that pertain to the channel during the previous century are present, then these should also be traced and included in the overlay. Such features include oxbow lakes (i.e., more recent meander cut-offs that continue to receive water during periods of high flow) and meander scars (i.e., dry depressions in the landscape that resemble a meander). **Figure 5.1** provides an example of an historic planform overlay for Carruthers Creek.

After the overlay has been assembled, and before the meander belt boundaries can be determined, several simple measurements and observations should be made:

- For the meanders that define the meander belt boundary (i.e., outer most meanders of the reach planform), the rate of lateral meander migration (i.e., across the floodplain) should be calculated. When no change in hydrologic regime is anticipated, the migration should be calculated using photos that represent approximately 20 – 30 year time interval before the most recent available photo. When a change in hydrologic regime is anticipated, then the rate of migration should be determined for the entire period of the historic information (i.e., earliest available and most recent coverage).
- Identify the position of meander belt axis for each historic reach position;
- If the meander belt axis has shifted, then the rate of the shift should be calculated;
- Identify evidence of relatively recent meander migration on the floodplain (e.g., meander scars, oxbow lakes, meander cut-off – width of channel in these features should be within several metres of existing channel width).

When there has been evidence of meander migration during the historic air photo record, then this information becomes particularly important in guiding the delineation of the meander belt. In each of the meander belt delineation procedures, the results of the historic analyses will be used to quantify with accuracy the meander belt width for the study area. **Section 3.6** outlines the process of delineating a meander belt by drawing upon the historic planform information.

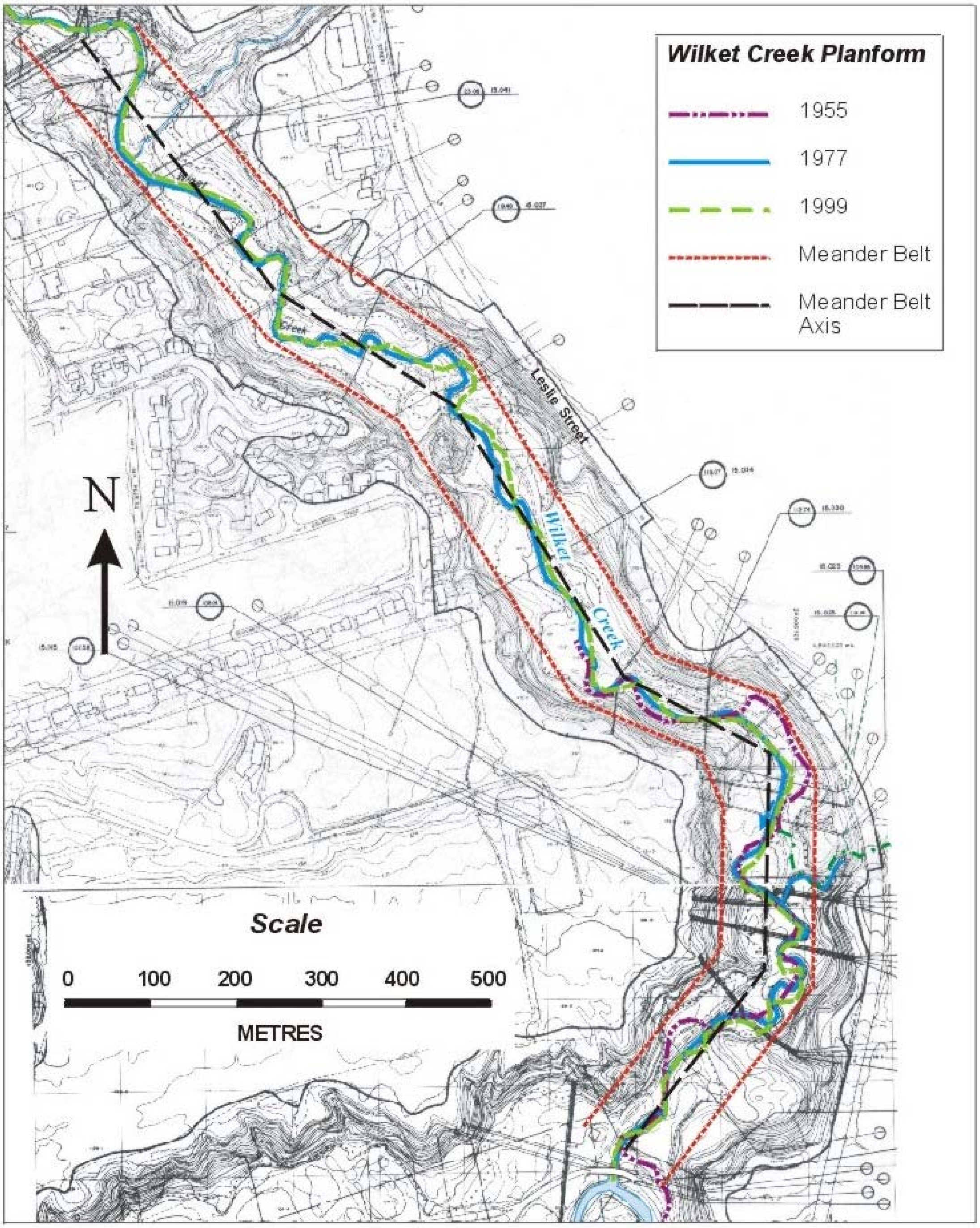


Figure 5.1: When completing historic analyses for Wilket Creek, floodplain features that represent a previous (i.e., ~ last 100 years) position of the reach on the floodplain was included

5.4.4 *Step 4: When the Watercourse has been Previously Altered*

When the planform configuration of the study area has been previously altered (e.g., straightened), then the affected section of the watercourse no longer represents the natural potential meander belt **(Figure 5.2)**. Hence, any measurement of the meander belt based on the altered planform configuration will be inaccurate. There are several alternatives or surrogate measures of the meander belt width that can be made which are identified below.

When a channel has been **altered, evidence of the natural configuration may be evident in the floodplain of the channel** (e.g., scars of infilled channel). Completion of historic air photo analyses would reveal whether the original configuration of the reach is evident in the floodplain **(Figure 5.2)**; If so, then the meander belt should be delineated based on the original unaltered configuration. **When the channel alteration occurred within the time period encompassed by the aerial photographs, then the unaltered channel configuration should be evident on one or more pre-alteration air photos.** In this case, and when the hydrologic regime of the watercourse has unlikely been altered, then the meander belt width should be determined based on the historic air photos
and any available topographic mapping that records the position of the unaltered channel configuration.

When there is no historical evidence of the natural planform configuration for the altered channel, then it is appropriate to estimate the meander belt width for the study area in another manner. Specifically, if the adjoining downstream reach is characterized by the same controls and modifying influences of planform as the altered study reach, then the planform of the downstream reach can be assumed to represent the planform of the previously altered channel **(Figure 5.3)**. If the downstream reach has different characteristics than the altered channel (i.e., in factors other than the planform), then the upstream reach can be considered to be a surrogate for the altered channel unless this reach also has different characteristics than the study area reach.

When there is no historical evidence of the natural planform configuration and when the downstream and upstream reaches have different controlling and modifying influences than the study area reach, then an alternative method of identifying the channel planform must be explored. Alternative methods include finding a reference reach along another watercourse that is identical to the study area reach (i.e., in hydrology, geology, land use, land cover) and drawing upon meander geometry relations or empirical formulae. Although finding a reference reach is ideal and preferred, the work required to evaluate the hydrologic regime for potential reference reaches along nearby watercourses is a time consuming process. Use of meander geometry relations and previously published empirical relations must be used cautiously since they are highly dependent on the data set (e.g., drainage area, geologic materials, climate, flow regime) from which they were derived. In many cases, the applicability of these

Figure 5.2: When an altered reach no longer occupies its potential meander belt, a reference to historic air photos or mapping often shows the natural configuration.

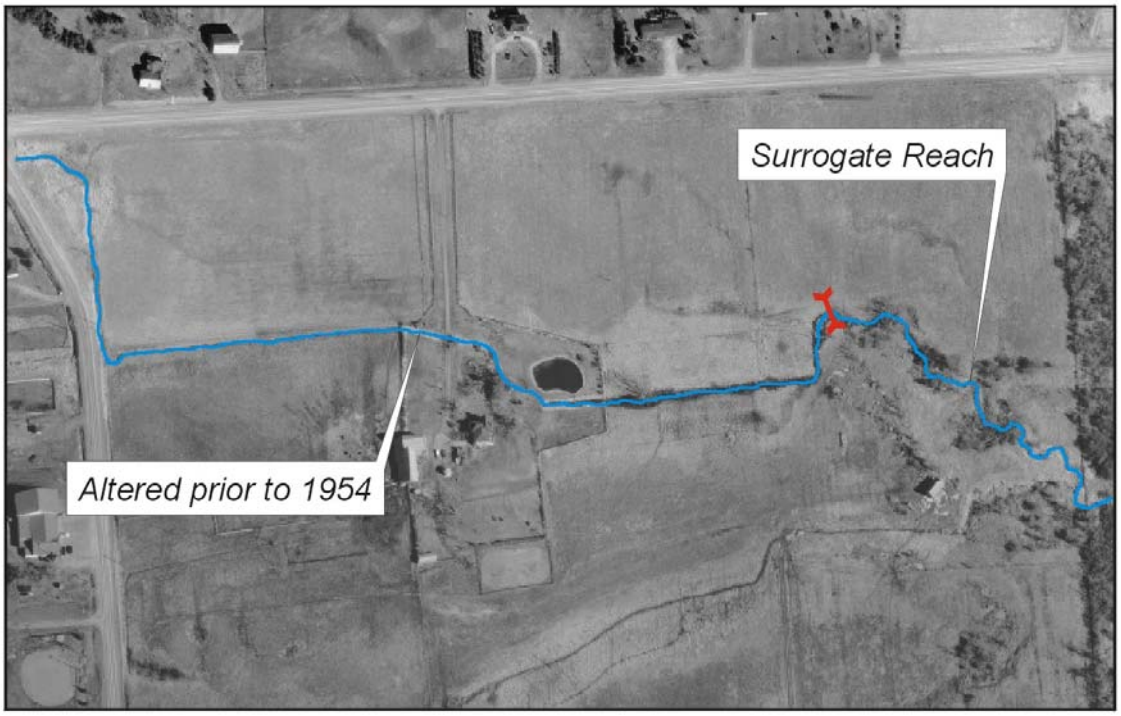


Figure 5.3: If historic air photos and/or mapping do not provide insight into the original natural configuration of the reach, then the meander pattern of a downstream (preferred) or upstream reach can be a surrogate.

relations and equations is inappropriate for Southern Ontario watercourses (see **Section 5.5.4** for a more detailed discussion). If an empirical relation appears to be the last resort for the process of quantifying the meaner belt, then ***Procedure 5*** should be followed. Use of ***Procedure 5*** when a surrogate reach can be identified is inappropriate and not advisable. If ***Procedure 5*** is the only method available to quantify the meander belt then the background work for the reaches is not necessary and the practitioner should proceed directly to **Section 5.5.4.**

When the meander configuration of the study area has been altered, then it is necessary to use an alternative method of defining and measuring the meander belt. The appropriate alternative method depends on whether there is historic evidence of the unaltered configuration for the study area, on whether adjoining reaches are representative of the study reach, and on whether a reference reach can be found to represent the study reach.

Whichever surrogate measure is to be used, the surrogate/study reach will, for the remainder of the document, be identified as the Reach. All methods that are described in ***Procedures 2 - 4*** apply to this Reach.

5.4.5 *Step 5: Field Reconnaissance*

General field reconnaissance of the (surrogate) reach should be completed to:

- Measure the width of the bankfull channel;
- To identify composition and stability of any valley walls;
- To determine whether the channel is actively incising into the floodplain.

5.5 Quantification of the Meander Belt

An overview of many of the watercourses that flow through Southern Ontario or indeed through the Greater Toronto Area reveals that there are many different meander configurations (i.e., natural or altered) and settings (e.g., unconfined, partially confined, confined or incised). Before beginning the meander belt delineation exercise, the following steps should have been completed:

Determine whether the meander belt will be delineated for the study reach or to a surrogate (e.g., downstream/upstream reach, reference reach along another watercourse);

Determine whether the watercourse consists of one or more reaches **(Section 3.4)**;

Identify the meander belt axis for the (surrogate) reach **(Section 3.5)**;

Identify the meander belt boundaries with attention to detail using 1:2,000 or larger scale mapping **(Section 3.6)**;

Complete appropriate historic analyses for the (surrogate) reach (i.e., depending on whether or not a change in hydrologic regime is anticipated) **(Section 5.4.3)**;

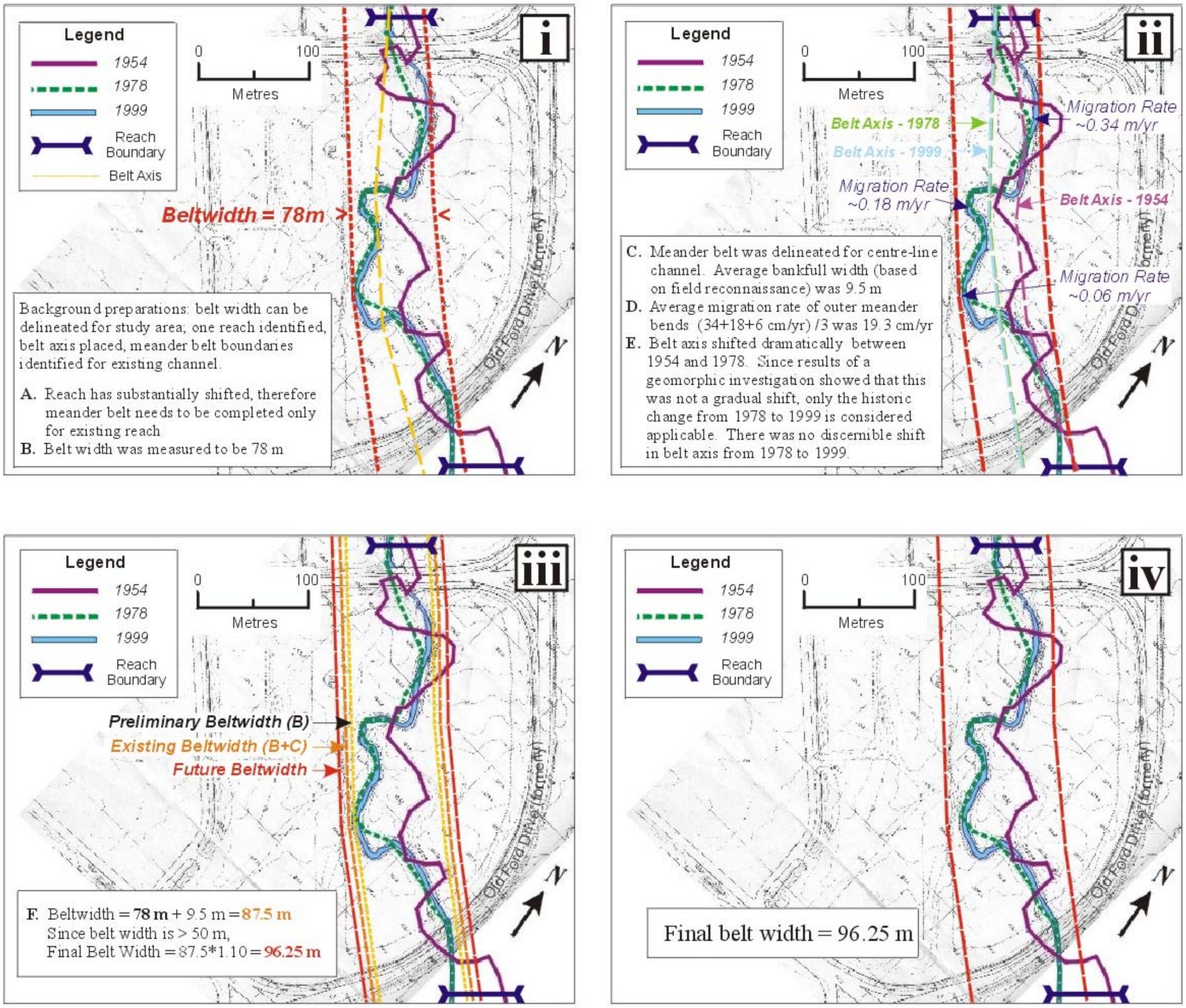
Conduct general field reconnaissance;

Once each of steps 1 – 5 **(Sections 5.4.1 – 5.4.5)** have been completed, the results can be combined and used to quantify the meander belt with precision. The methods used to quantify the meander belt will vary depending on whether or not a change in hydrology is anticipated.

If a watercourse is particularly sensitive to both the scope and magnitude of the proposed works in or around the watercourse as ascertained by the Toronto and Region Conservation Authority, then it is recommended that a more detailed investigation into the existing and future potential meander belt be completed. This type of work is beyond the scope of this protocol and should only be undertaken by a qualified fluvial geomorphologist with relevant technical support that can be provided by an interdisciplinary study team (i.e., water resource engineer).

5.5.1 ***Procedure 2 –*** *no change in hydrology is anticipated*

Having completed the background preparatory work (i.e., reach delineation, meander belt boundaries, historic analyses), substantial progress has been made towards defining the meander belt width for the reach within the study area. The procedure outlined below combines the results of the background work that has been completed. **Figure 5.4** provides a visual illustration of the accurate meander belt delineation process for ***Procedure 2***.



Background preparations: belt width can be delineated for study area; one reach identified, belt axis placed, meander belt boundaries identified for existing channel.

A. Reach has substantially shifted, therefore meander belt needs to be completed only for existing reach

B. Belt width was measured to be 78 m

C. Meander belt was delineated for centre-line channel. Average bankfull width (based on field reconnaissance) was 9.5 m

D. Average migration rate of outer meander bends (34+18+6 cm/yr) /3 was 19.3 cm/yr

E. Belt axis shifted dramatically between 1954 and 1978. Since results of a geomorphic investigation showed that this was not a gradual shift, only the historic change from 1978 to 1999 is considered applicable. There was no discernible shift in belt axis from 1978 to 1999.

F. Beltwidth = **78 m** + 9.5 m = **87.5 m**
Since belt width is > 50 m,
Final Belt Width = 87.5*1.10 = **96.25 m**

Final belt width = 96.25 m

Figure 5.4: **Procedure 2** is applied to a reach of Joshua Creek for which no change in hydrology is anticipated. (i) identifies calculations described in **Section 5.5** (ii) identifies the calculations of the historic assessment (C,D,E); (iii) preliminary belt width calculation; (iv) applies the predicted belt width to the reach

A. Check the position of the meander belt boundaries, ensuring that they account for the position of any historic floodplain features and that they are reasonably parallel to the meander belt axis;

B. Measure the width of the meander belt perpendicular to the belt boundaries;

C. If the meander belt was delineated using maps or photos that portray only the centre-line of the channel, then determine the average bankfull channel width **(Section 5.4.5)** of the reach;

D. Referring to the rates of migration that were determined for the meander bends that are situated at, or in proximity to, the meander belt boundaries, calculate an average migration rate. Calculate the 100 year migration distance using the average migration rate. NOTE: the rate is calculated only for an approximately 30 year interval preceding the most recent historic planform information that is available;

E. If the position of the meander axis has shifted on the floodplain as determined through the historic analyses, then calculate the distance that the meander axis will shift during a period of 100 years by assuming that the rate of shifting remains constant during this time period.

F. The preliminary belt width is calculated as follows:

Preliminary Belt Width = B (Eq. 1)

Existing Belt Width = B + C (Eq. 2)

To account for the fact that the existing meander belt does not necessarily reflect a quasi-equilibrium form, a factor of safety must be added to the measured width of the meander belt (see **Appendix C**).

If the belt width is < 50 m:

Final Belt Width = Belt Width + D + E (Eq. 3)

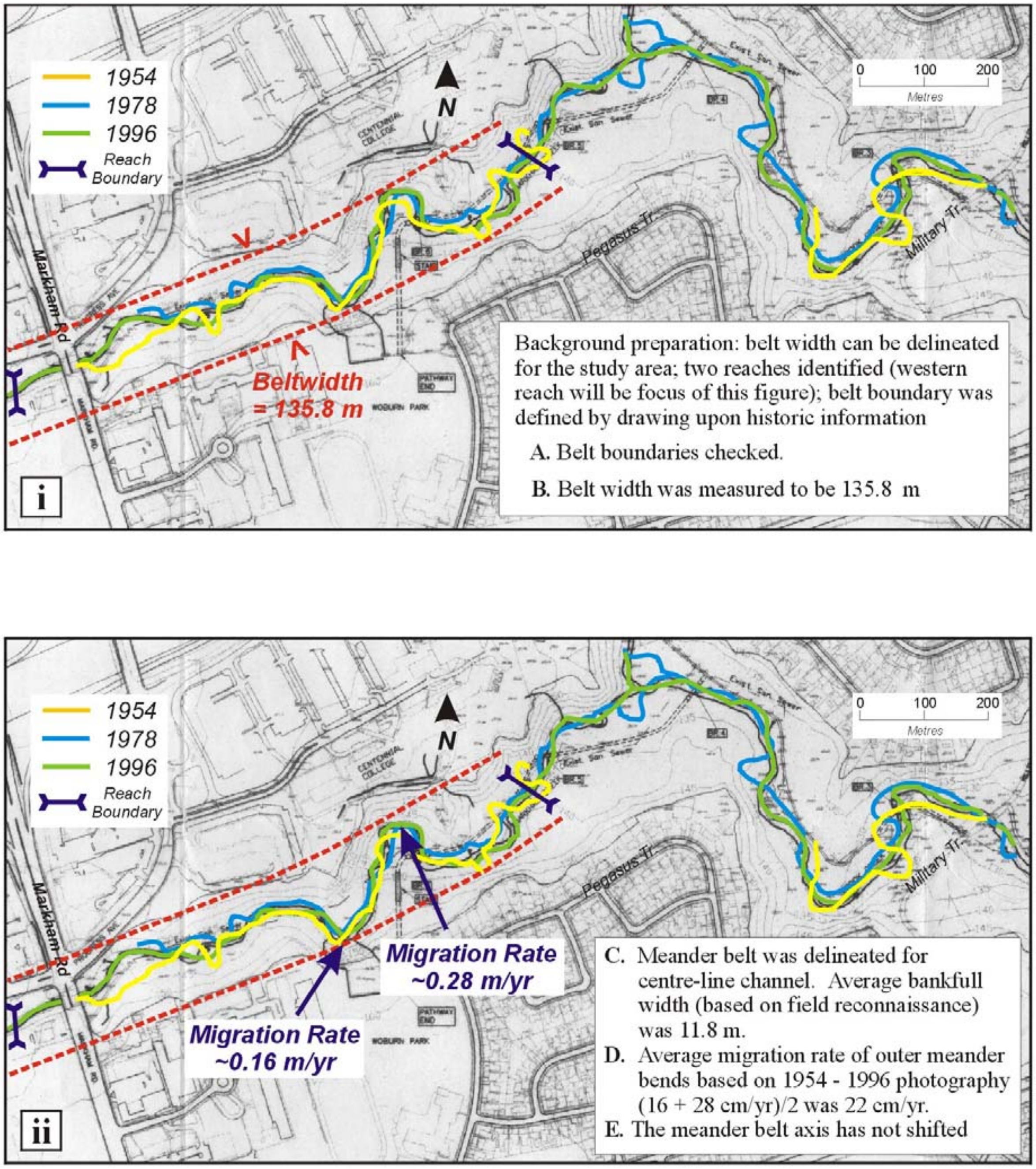
If the belt width is > 50 m:

Final Belt Width = Belt Width *1.10 + E (Eq. 4)

Some interpretation may be required for sites that have a belt width of 50 m (40 m to 60 m). Both approaches should be completed, with the more conservative value selected (**Appendix C**)

5.5.2 ***Procedure 3*** *- Change in Hydrologic Regime – Flow duration and frequency*

Whenever land use/cover of an area is altered, then there are implications to the hydrologic regime of the receiving watercourse. Through storm water management practices, the impact of the land use/cover changes are minimized. Nevertheless, there will most often be an increase in duration of the flows and in frequency of occurrence. In these situations, the following actions should be taken to quantify the meander belt (see **Figure 5.5** for an illustration of each step outlined in ***Procedure 3***):



Background preparation: belt width can be delineated for the study area; two reaches identified (western reach will be focus of this figure); belt boundary was defined by drawing upon historic information

A. Belt boundaries checked.

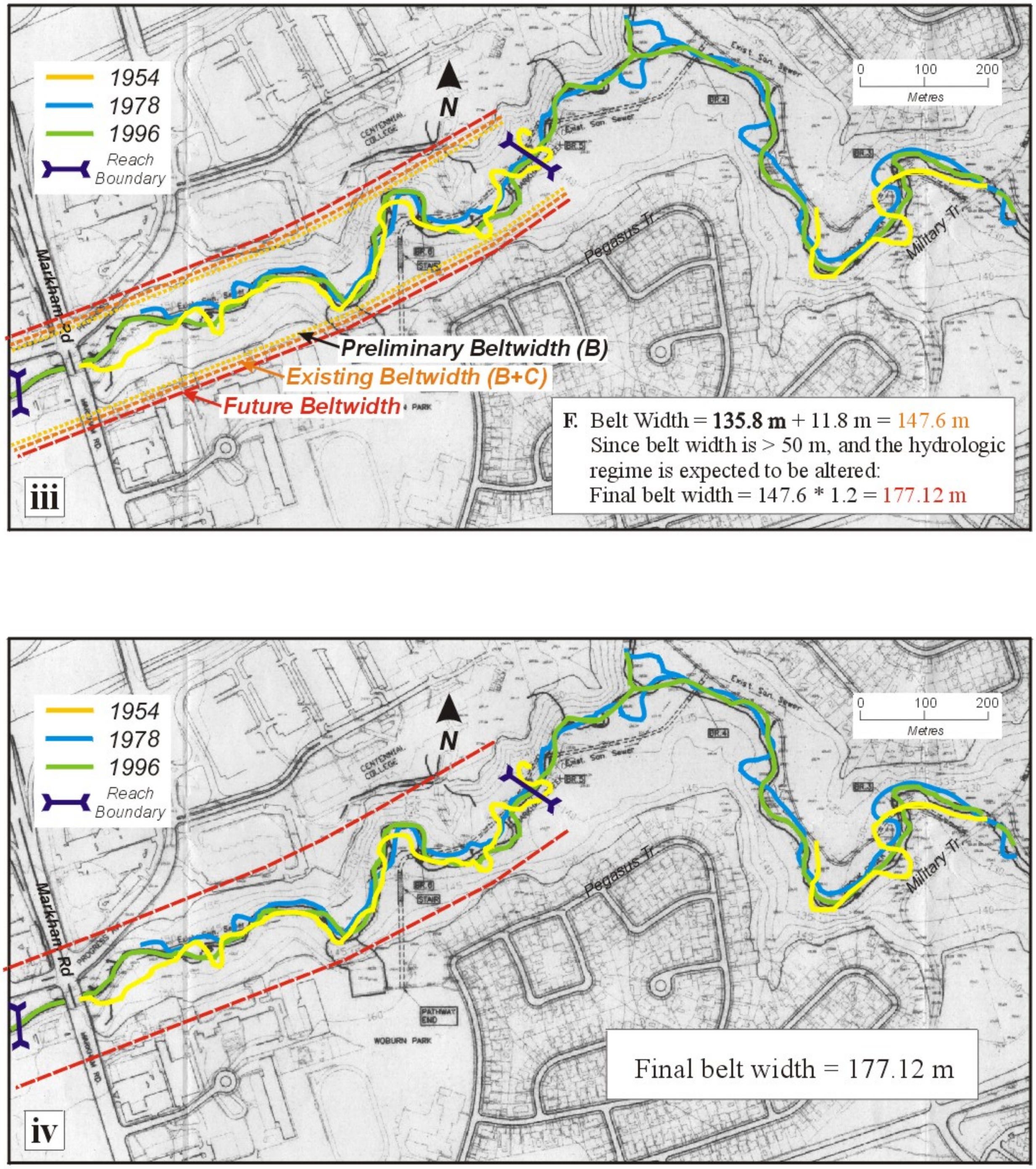
B. Belt width was measured to be 135.8 m

C. Meander belt was delineated for centre-line channel. Average bankfull width (based on field reconnaissance) was 11.8 m.

D. Average migration rate of outer meander bends based on 1954 - 1996 photography (16 + 28 cm/yr)/2 was 22 cm/yr.

E. The meander belt axis has not shifted

Figure 5.5: **Procedure 3** is applied to a reach of Highland Creek for which a hypothetical change in hydrologic regime is expected. (i) identifies calculations described in **Section 5.5**; (ii) identifies the calculations of the historic assessment (D, E); (iii) preliminary belt width; (iv) applies the predicted belt width to the reach



F. Belt Width = **135.8 m** + 11.8 m = 147.6 m
Since belt width is > 50 m, and the hydrologic regime is expected to be altered:
Final belt width = 147.6 * 1.2 = 177.12 m

Final belt width = 177.12 m

Figure 5.5 (con't): **Procedure 3** is applied to a reach of Highland Creek for which a *hypothetical* change in hydrologic regime (i.e., flow duration and frequency) is expected. (iii) shows the calculation of the preliminary belt width; (iv) applies the predicted belt width to the reach.

A. Check the position of the meander belt boundaries, ensuring that they account for the position of any historic floodplain features and that they are reasonably parallel to the meander belt axis;

B. Measure the width of the meander belt perpendicular to the belt boundaries;

C. If the meander belt was delineated using maps or photos that portray only the centre-line of the channel, then determine the average bankfull channel width **(Section 5.4.5)** of the reach;

D. Referring to the rates of migration that were determined for the meander bends that are situated at, or in proximity to, the meander belt boundaries, calculate an average migration rate. Calculate the 100 year migration distance using the average migration rate. NOTE: the rate is calculated for the entire time period covered by the historic photos (i.e., from earliest available to the most recent)

E. If the position of the meander axis has shifted on the floodplain as determined through the historic analyses (earliest to most recent photo), then calculate the distance that the meander axis will shift during a period of 100 years;

F. The preliminary belt width is calculated as follows:

Preliminary Belt Width = B (Eq. 1)

Existing Belt Width = B + C (Eq. 2)

To account for the fact that the existing meander belt does not necessarily reflect a quasi-equilibrium form, a factor of safety must be added to the measured width of the meander belt (see **Appendix C**).

If the belt width is < 50 m:

Final Belt Width = (Belt Width * 1.05) + D + E (Eq. 5)

If the belt width is > 50 m:

Final Belt Width = Belt Width *1.20 (Eq. 6)

5.5.3 ***Procedure 4****: Change in Hydrologic Regime – Peak Flow and frequency*

Although current storm water management practices within Southern Ontario match post – pre development peak flows of the receiving watercourses, occasionally, peak flows are proposed to increase. In this scenario, quantification of the meander belt is somewhat different than described for the preceding procedures. **Figure 5.6** illustrates the application of **Procedure 4**.

A. Check the position of the meander belt boundaries, ensuring that they account for the position of any historic floodplain features and that they are reasonably parallel to the meander belt axis;

B. Measure the width of the meander belt perpendicular to the belt boundaries;

C. If the meander belt was delineated using maps or photos that portray only the centre-line of the channel, then determine the average bankfull channel width **(Section 5.4.5)** of the reach;

D. If the position of the meander axis has shifted on the floodplain as determined through the historic analyses (earliest to most recent photo), then calculate the distance that the meander axis will shift during a period of 100 years;

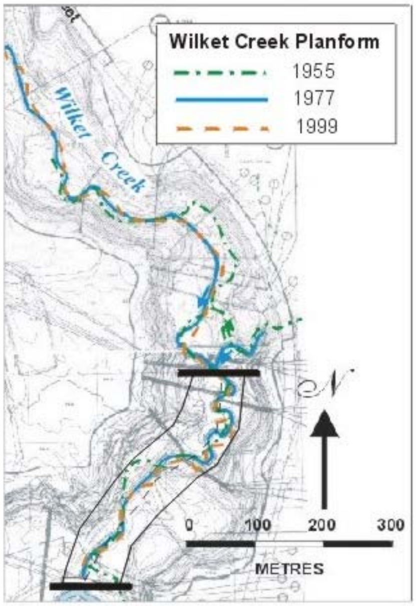
E. Quantify the pre – and post – development 2 year peak flows and calculate the adjustment ratio:

$$\text{adjustment ratio} = \frac{Q_2\text{post}}{Q_2\text{pre}} \qquad \text{(Eq.6)}$$

(Note: this ratio is considered to be appropriate since it defines a ratio of relative increase in peak flows from existing conditions. Since the meander belt is a function of flows, an increase in peak flows would be expected to cause an increase in belt width)

F. The meander belt width is calculated as follows:

$$\text{Belt Width} = (B + C + D) * \text{adjustment ratio} \qquad \text{(Eq. 7)}$$



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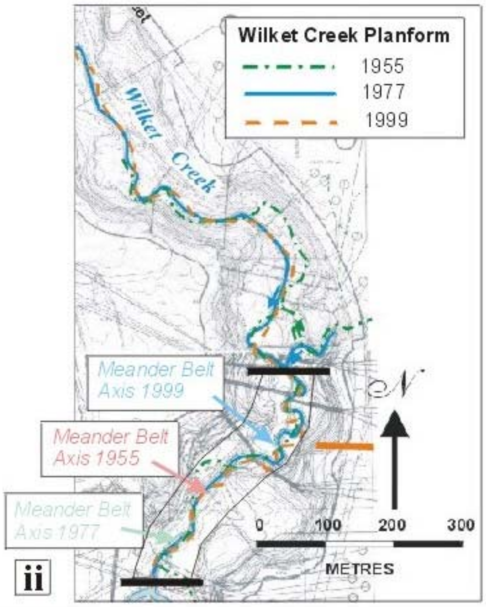
Background Preparation: belt width can be delineated for the study area; two reaches identified (downstream reach will be focus of this figure); belt boundary was defined by drawing upon historic information.

- **A.** Belt boundaries were checked
- **B.** Belt width was measured to be 88.45 m



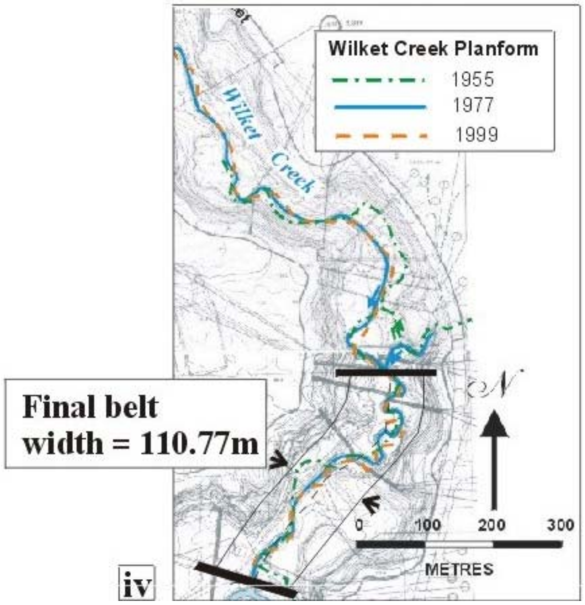
ii

- **C.** Meander belt was delineated for centre-line channel. Average bankfull width (based on field reconnaissance) was 10.45 m
- **D.** Position of meander axis has remained essentially unaltered

iii

- **E.** The hypothetical change in flow regime will cause peak flows in the channel to increase from 22.3 cms (pre) to 25 cms (post). The adjusment ratio is: 25/22.3 = 1.12.

- **F.** The meander belt was calculated as (88.45+10.45+0)m * 1.12 = 110.77 m



iv

Figure 5.6: **Procedure 4** is applied to a reach of Wilket Creek for which a hypothetical change in hydrologic regime is expected. (i) identifies calculations described in **Section 5.5**; (ii) identifies the calculations of the historic assessment (D, E); (iii) preliminary belt width; (iv) applies the predicted belt width.

5.5.4. ***Procedure 5**. Accurate Meander Belt Delineation - Empirical Approach*

Many sections of channel have been altered, often in conjunction with agricultural land use but also in conjunction with urbanization. When a channel has been straightened, but not reinforced through hard engineering then, through time, the river will re-establish a natural planform configuration that is in quasi-equilibrium with its modifying and controlling factors. Thus, although a channel has been straightened and the meander belt effectively eliminated, through time, the watercourse will re-occupy its meander belt (for example see: Newbury and Gaboury (1993)). The time required for an altered channel to re-occupy its meander belt is dependent on numerous factors. For planning or rehabilitation purposes, estimation of the floodplain width that the watercourse may occupy in the future is necessary. Knowledge of an approximate width is also necessary for rehabilitation purposes so that the proposed watercourse configuration is within the natural limits of floodplain occupation.

Most of the previously altered watercourses that are in headwater areas, especially in agricultural areas occurred prior to the date of earliest available aerial photographs. Thus, the natural meander configuration cannot often be used as a surrogate for belt width estimation unless this has remained evident in the floodplain. As discussed throughout this document and section specifically, the best way of defining a meander belt for a given reach is to draw upon the existing meander configurations and, if these are not available or reliable, then to draw upon the meander configurations of adjacent or nearby reaches. Most often, the altered channels that are in agricultural areas have a low order (1st or 2nd) and a long length. As such, reference reaches as a surrogate for the meander configuration are not always available and therefore, determination of a meander belt width that is based on physical characteristics of the reach or a surrogate thereof does not appear to be plausible.

To enable an approximation of the meander belt for a given reach in which the natural meander configuration is no longer evident, and for which no surrogate reaches area available, an alternative procedure has been developed. This procedure uses an empirical relation that predicts meander belt width from drainage area and stream power of the watercourse. Relevant information pertaining to the appropriate application of the relation is presented in the following sub-sections.

5.5.4.1 Conditions for application of Empirical Formula

The empirical relation was developed from data for watercourses that satisfied the following criteria:

- Reach should not be confined, but may be partially confined;
- No previous alterations to planform configuration;
- No previous human induced changes to hydrologic regime (e.g., diversion, on-line ponds);
- Not situated on bedrock;
- Rural setting (any land-use)
- Drainage area < 25 km^2

It follows that the appropriate application of the derived empirical formula is for reaches that satisfy the same criteria as those used in the data set.

5.5.4.2 Input Data

To apply the empirical relation, the following data are required:

- Drainage area (in km^2)
- Gradient of reach (i.e., of channel, not valley slope, measured in m/m)
- 2 year flow

5.5.4.3 The Empirical Relation

The empirical relation that was developed for this procedure is as follows:

$$SP = \gamma Q s \qquad \text{(Eq. 8)}$$

$$Wb = -14.827 + 8.319 \ln(SP * DA) \qquad R^2 = 0.739 \quad S = 8.63 \qquad \text{(Eq. 9)}$$

Where:
SP = stream power (Wm^{-2})
γ = specific weight of water (9806 kg/m^2s^2)
Q = 2 year flow (m^3s^{-1})
s = channel gradient (m/m)
Wb = meander belt width (m)
DA = drainage area (km^2)
R^2 = Correlation coefficient of regression
S = standard error of equation

The data set from which **Equation 9** was developed was characterized by some scatter both above and below the curve. For those data points, the equation either under or over predicts the actual width of the meander belt. It is expected that similar predictions for reaches with unknown meander belt widths would be similarly under or over predicted. Under prediction of the meander belt is the least desirable scenario for planning purposes as this could have detrimental implications. For this reason, it is recommended that the standard error term associated with **Equation 9** be added to the estimated meander belt width as a factor of safety to allow for potential under prediction of the actual meander belt while also allowing for natural migration tendencies. The standard error should be applied as follows:

No change in hydrologic regime is anticipated:

Meander Belt Width = Equation 9 + standard error

A change in hydrologic regime is anticipated:

Meander Belt Width = Equation 9 + 2 * standard error

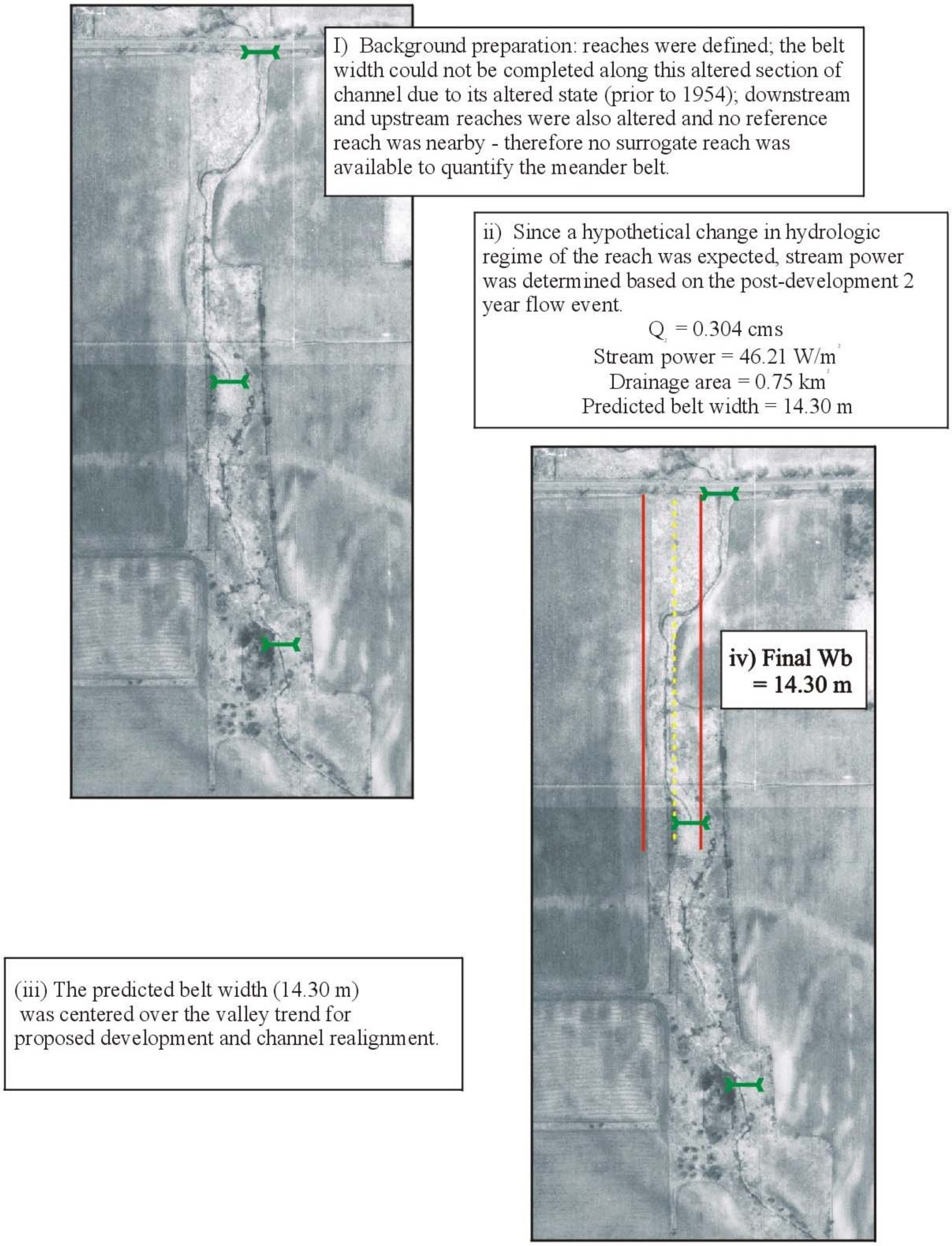
The meander belt width that has been quantified should be centered around the meander belt axis. **Figure 5.7** illustrates the application of **Procedure 5**.

5.5.4.4 Use of Previously Published Relations

Relations between various channel parameters and the meander belt width have been published in the literature. While these relations are valid and based on measurements of real watercourses, the transferability of these relations to the watercourses that are situated within Southern Ontario is limited. The limitations are due to the difference in hydrologic regime, drainage area, general controlling factors (e.g., surficial geology, gradient) that play an important role in determining the belt width of a watercourse. Work completed by Annable (1996a) consists of planform measurements of 47 watercourses that are largely situated within Southern Ontario. Annable classified each of the watercourse reaches using Rosgen's

(1994) system and then proceeded with analyses to identify regional relations between various parameters of the meander planform.

Given that Annable derived his empirical relations from data gathered in Southern Ontario, it would appear that these relations could approximate the meander belt width for the purpose of **Procedures 2 - 4**. Annable (1996b) clearly states that there does not appear to be a high degree of reliability or reproducibility within the relations ($r^2 < 0.38$), and that the relations are most suitable as "…first-order approximations of gross-scale channel characteristics related to basin scale studies. The relations … are typically associated with large-scale estimations such as those obtained from mapping or air photos to gain a general insight into the dynamics of a river relative to the watershed and valley scales." (Annable, 1996b, pg. 18). Thus, although Annable's relations would appear to be suitable for general level studies, for the purpose of accurate meander belt delineation it is clearly not suited. Furthermore, the watercourses included in Annable's data set had drainage areas that were > 18.9 km^2 and bankfull discharges that were > 2.27 m^3s^{-1}. Although a few of the lower values are representative of the general conditions of the watercourses for which the meander belt is likely to be quantified, most of the data are not (i.e., have much larger flows and drainage areas). For these reasons, the empirical relation that has been produced for this study is considered to be more appropriate for quantifying the meander belt of watercourses that flow within the jurisdiction of the Toronto and Region Conservation Authority. It is anticipated that, as more data become available, the equation would be modified and, therefore, may change in time.



I) Background preparation: reaches were defined; the belt width could not be completed along this altered section of channel due to its altered state (prior to 1954); downstream and upstream reaches were also altered and no reference reach was nearby - therefore no surrogate reach was available to quantify the meander belt.

ii) Since a hypothetical change in hydrologic regime of the reach was expected, stream power was determined based on the post-development 2 year flow event.

$Q_2 = 0.304$ cms
Stream power = 46.21 W/m^2
Drainage area = 0.75 km^2
Predicted belt width = 14.30 m

(iii) The predicted belt width (14.30 m) was centered over the valley trend for proposed development and channel realignment.

iv) Final Wb = 14.30 m

Figure 5.7: **Procedure 5** was the most appropriate method for quantifying the meander belt for a reach along a tributary of Oshawa Creek because through background work it was apparent that it had been altered and that no appropriate surrogate was available to assess its meander belt.

Nevertheless, for the purpose of the meander belt delineation protocol, at this time, it is considered to be appropriate and reliable and therefore should be used in lieu of any other previously published empirical relation.

5.6 Summary

The planform pattern of watercourses represents a balance between the hydrologic regime that is conveyed through it and all of the controlling and modifying influences of the planform. When the hydrologic regime remains relatively unaltered with respect to those components that are influential in affecting the meander configuration for a particular Reach, then the existing planform for that Reach can be expected to be relatively representative of the future meander configuration and floodplain occupation. Since the observed planform configuration does not necessarily reflect the quasi-equilibrium form (i.e., since it may be in adjustment to previous hydrologic changes or to long-term trends in precipitation patterns), it is likely that the width of the meander belt will change in the future. The meander belt width procedures that have been described in this chapter enable a reasonably accurate estimate of the belt width by assuming that the observed planform configuration is not yet in a quasi-equilibrium state and drawing upon historic tendencies of the watercourse.

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APPENDIX A

Glossary of Terms

APPENDIX A

Glossary of Terms

Bankfull Discharge – is, conceptually the flow that fills the channel just prior to spilling onto the floodplain. In a watercourse that is in equilibrium with respect to its controls and modifying influences, bankfull discharge is the same as the dominant discharge. Statistically, in rural watercourses, bankfull discharge occurs once every 1.6 years. In urban settings, the frequency of bankfull discharge increases and may occur 2 or more times per year. Bankfull flow stage is typically defined by field indicators and in most instances is actually located below the top-of-bank.

Compound meander – description of an entity consisting of more than one defining component. A compound meander configuration has both a primary and secondary meander pattern.

Confined watercourse – when the lateral movement of a watercourse is constrained due to the presence of valley walls or a resistant geologic outcrop on both sides of the meander belt.

Dominant Discharge – the channel defining flow or the flow to which the channel form (i.e., cross-section, planform, profile) has adjusted. This value may be equal to, or greater than, the bankfull discharge.

Fluvial Geomorphology – the scientific study concerned with landforms associated with flowing water, especially the origin, evolution, and processes of streams and rivers.

Geomorphology – the scientific study concerned with landforms, especially the origin, evolution, and processes involved with the formation of the surface forms of the earth.

Gradient – the slope of a surface as determined by the quotient of rise over run.

Incised watercourse – the term applied to any watercourse that has a tendency for bed degradation rather than lateral migration. Often such a channel will have a narrow or non-existent floodplain and can be in a ravine or valley. Contour lines are close together and have a distinct V-shaped configuration

Irregular – describing an entity without predictable qualities. For example, a section of a meandering watercourse that is characterized by a range of meander wavelengths, amplitude, and radius of curvature.

Land cover – the term used to describe the material (natural or artificial) covering the surface of the land (e.g., forest, water, pavement). Compare: land use.

Land use – the term applied to the use made by human beings of the surface of the land (e.g. plantation forest, housing, reservoir, parking lot). Compare: land cover.

Meander belt –the land area on either side of a watercourse representing the farthest potential limit of channel migration. Areas within the meander belt may some day be occupied by the watercourse; areas outside of the meander belt will not.

Meander configuration – see 'planform'

Meander evolution – physical changes in a meander (cross-section, long profile) as caused by long-term processes of erosion (e.g. outside of bend) and deposition (e.g. inside of bend).

Partially confined watercourse – when the lateral movement of a watercourse is restricted on one side of its meander belt due to the presence of a valley wall or resistant geologic outcrop. Migration or movement of the watercourse on the other side of the meander belt is uninhibited.

Planform – the course of a river, as visualized on a two-dimensional surface, such as on a map or aerial photograph.

Reach – a longitudinal section of a watercourse that displays fairly consistent physical characteristics, such as substrate materials, channel dimensions, and gradient. The controls and modifiers of channel form are similar along the reach.

Regular – describing an entity with predictable qualities. For example, a section of a meandering watercourse that is characterized by a common frequency, radius of curvature and amplitude.

Simple meander – description of an entity consisting of one defining component. In simple meander patterns, the meanders follow a general linear or quasi-linear down-valley trend.

Sinuosity – Sinuosity is a measure of the degree of channel meandering, represented numerically by the ratio of stream length to valley length.

Stream order – a stream classification system based on the number of upstream branches or tributaries possessed by a particular drainage network. Unbranched streams are classified as first order. When two first order streams confluence, the resultant stream becomes a second order. Whenever two streams of equal order (n) confluence, the resultant downstream channel is given a number of (n + 1). If a lower order tributary joins the main channel, the stream order does not change. The objective of the classification system is to be able to describe a link in the drainage network anywhere in the world in an unambiguous manner, and also to provide an ordering system that can readily provide an indication of discharge from a network.

Stream Power – is a calculated quantity that represents the rate of energy that is available to do work (i.e., transport sediment) per unit length along a channel.

Unconfined – refers to a watercourse that is able to migrate freely on its floodplain in any direction.

APPENDIX B

Background Information

APPENDIX B

Background Information

Introduction

Watercourses are dynamic systems and, to gain a full appreciation and understanding of the various system components and how they function individually and together in a channel takes a substantial amount of time and investigation. In Southern Ontario, the spatial variability of floodplain materials and of the landscape, create a diversity of channel systems. For the purpose of the meander belt width delineation protocol, a general description of the important elements and processes that affect the meander belt was provided in **Chapter 2**. Further information, which has been subjected to a peer review, is provided in this appendix to provide the practitioner with further insight into some of the processes and concepts that were introduced within the main text of this document.

To develop a working policy that protects the integrity of a river corridor and surrounding land, while minimizing interference with the natural tendencies of the river, it is important to have an understanding of the physical processes that are operative in meandering channels. In this appendix, various properties and formative processes that contribute to the development of river meanders are described and discussed. The discussion is not meant to be a comprehensive overview of meandering rivers, but is intended to provide background information that is relevant to understanding the position and migration of a river on its floodplain.

Meander Geometry

The meandering river pattern can be described by various geometric variables that include wavelength (λ), bankfull channel width (w), amplitude (A) and radius of curvature (Rc) **(Figure B1)**. In most rivers, there tends to be a strong correlation between these variables, and with discharge, enabling the development of empirical formulae known as meander geometry relations which can be useful for prediction purposes (Leopold and Wolman, 1960). Because the correlations are strong, different sized rivers will appear similar on air photos, making it difficult to ascertain the actual size of the river based on air photo analyses alone. Indeed, Leopold and Wolman (1960) observed that the meanders of all rivers tend to be scaled versions of the same set of geometric variables.

Both amplitude and belt width are terms that quantify the lateral extent of a river's occupation on the floodplain. Because the distinction between meander amplitude and meander belt width is not always clear to the non-river scientist, it warrants a brief discussion here. Leopold et al., (1964) define meander amplitude as the lateral distance between tangential lines drawn to the centre channel of two successive meander bends **(Figure B2)**. Therefore, the amplitude is measured only from a meander crest to a meander trough or vice versa. The width of a meander belt is measured normal to tangential lines drawn to the outside bends of a sequence of meanders.

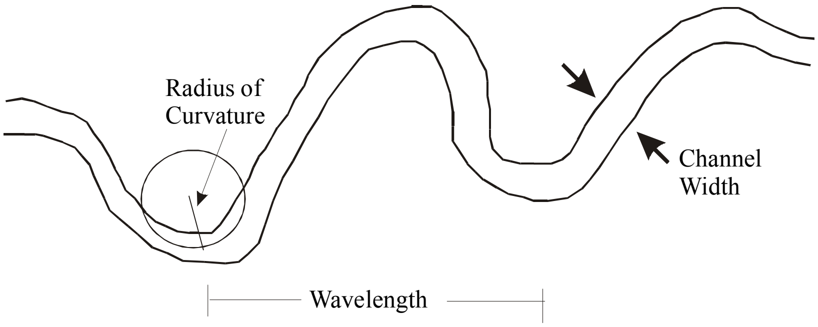

Figure B1. Schematic diagram of a meander pattern, defining meander wavelength, radius of curvature and channel width.

The precise pattern and dimensions of a meandering planform, and both the rate and direction of migration are in quasi-equilibrium with, and a function of, discharge, bedload, valley slope and resistance of channel bed and bank materials (Matthes, 1941; Gregory and Walling, 1973; Knighton, 1998). If the floodplain is relatively homogeneous in composition, then a regular meander pattern will develop. If the floodplain contains lenses, strata or deposits of resistant material, then the meander pattern tends to become irregular. When the discharge and/or sediment regimes of a river change in response to human activities (i.e. land clearing, urbanization, creation of lakes, irrigation (Burke, 1984)), or in response to natural changes within the watershed, then the boundaries of the river will adjust to minimize energy expenditure.

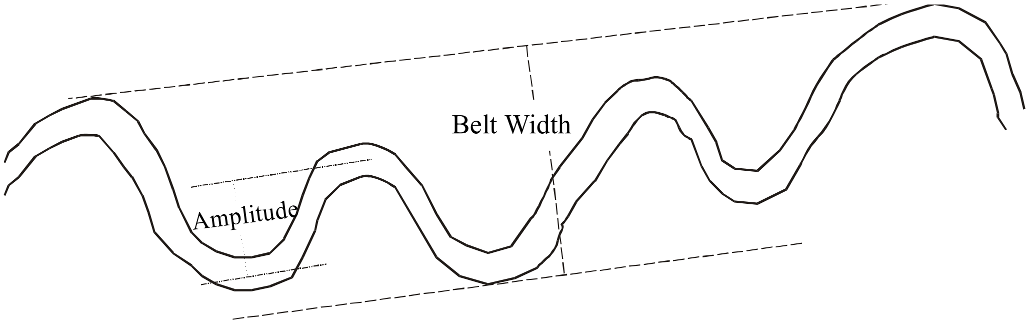

Figure B2. The belt width (Wb) is defined as the distance between tangents drawn to the outside bends of a series of meanders. Meander amplitude (A) is measured between successive meanders.

Migration Tendencies

In response to changes in flow and sediment regimes (land use or climatic change), the channel pattern adjusts to gain a state of balance between all the factors that influence its planform. Changes in planform also occur due to the different erodibilities of floodplain or valley wall materials which often affect migration rates and directions. Channel migration occurs in most naturally meandering watercourses and is considered to be an equilibrium process (i.e. includes both deposition and erosion of floodplain materials). When the upstream limb of a meander bend migrates more rapidly than the downstream limb or significant changes to flow and sediment regimes have occurred, then meander cut-offs may occur. Floodplain evidence that provides insight into migration history includes oxbow lakes and meanders scars in proximity to the river. Any river that migrates does so laterally across a floodplain and/or in the downstream direction. The process of migration does not occur simultaneously along the entire length of the channel but, rather, occurs at discrete locations at any one time (Burke, 1984; Hagerty, 1984; Chang, 1992). In the following subsections, both the direction and rates of migration will be discussed since both of these affect the width of the meander belt.

Lateral and Downstream Migration

As part of an equilibration process between channel planform and controlling factors such as valley gradient, boundary materials, water and sediment regimes, channel incision or meander migration may occur. Through rotation and extension of the meander bend, the river may migrate laterally across the floodplain, down-valley or assume both pathways simultaneously. Resistant materials in the floodplain may interfere with the direction of meander migration, contributing to an irregular planform.

The relation between channel flow and channel shape, a function of the radius of curvature (Rc) of a channel, will affect the direction and rate of meander migration and development. When the flow and channel patterns are out-of-phase then the meander bend will migrate down-valley/stream (Chang, 1992). Most channels, especially stable channels, migrate downstream. Chorley et al. (1984) show that, on average, only 10 – 20 % of flow energy is expended in the lateral direction in concave meander bends. Most scour occurs in the direction opposite of the point bar apex. If the flow and channel patterns are in-phase (i.e. parallel so that thalweg follows same pattern as planview), then the meanders will migrate laterally across the valley.

Rate of Migration

The migration rate (M) of a meander bend is a function of discharge (Q), water-surface slope (s), boundary material (c), concave bank height (h), bank vegetation (v), the ratio of radius of curvature and channel width (Rc/w), and distribution of shear stress in a channel cross-section (Hickin and Nanson, 1975):

$$M = f(Q, s, c, h, v, Rc/w) \tag{B1}$$

In general, migration rates increase with an increase in discharge or water-surface slope and are most rapid when the bank material is non-cohesive (e.g. sands). When the slope, bank material, bank height and vegetation remain constant, the migration rate appears to be affected most by the shape of the bend, expressed as the radius of curvature:channel width ratio (Rc/w) (Hickin and Nanson, 1975). Various studies have shown that, on average, most rivers exhibit a Rc/w ratio that is between 2 and 3 (Leopold and Wolman (1960); Hickin (1974); Williams (1986)).

When the radius of curvature of a river is not in equilibrium with the flow regime, then adjustments occur within the channel that change the radius towards an equilibrium relation with the flow. Hooke (1975) observed that if the Rc is too large, then the upstream limb of the meander will migrate more quickly than the downstream limb. The opposite migration tendency occurs when the Rc is too small (i.e. the downstream limb will move more quickly). If migration of the downstream limb is impeded by local geology or geomorphology and the upstream limb continues to move downstream then, through time, both limbs will meet. Channel avulsion will cause the meander bend to be abandoned as water seeks a direct route downstream that requires the least amount of work.

Meander Belts

Meander belt initiation and development are driven by discharge and are limited by properties of the floodplain. Because properties of the floodplain (e.g. sediment composition, valley gradient, riparian vegetation) vary spatially, the belt width of a watercourse will vary in the downstream direction.

Definitions

Conceptually, the terms meander belt width, meander width, belt width, or river corridor (Gurnell, 1995) are synonyms which describe the lateral containment of a river channel on a land surface. Technically, the meander belt width is quantified as the distance normal to tangential lines drawn to outside bends of the meanders within the reach of interest (Fig. 2.2) (Leopold and Wolman, 1960; Carlston, 1965; Chang and Toebes, 1970; Annable, 1996b).

Some rivers migrate actively across the floodplain, as evidenced by the presence of meander scars, oxbow lakes and meander cut-offs. Accounting for this tendency, Jefferson (1902), Matthes (1941), and Leeder and Alexander (1987) define the meander belt width as the distance between the furthest extent of abandoned meanders and meander scars on the floodplain surrounding the river. To account for the evolutionary process of a river, Woltemade (1994) and Lecce (1997) define the meander belt width as the valley portion that is flat between terraces or valley walls surrounding the river.

The pattern of a meandering channel rarely follows a symmetrical sine wave around a linear downstream oriented axis. As such, the technical definitions of meander belt width that have been presented thus far do not fully account for the potential downstream migration of the channel pattern since these assume a regular meander pattern that follows a linear trend down-valley. For this reason, Carson and Lapointe (1983) suggest that the meander belt axis should follow the trends of the meandering pattern, especially when the meanders are asymmetric and irregular **(Figure B3a)**. A belt width defined in this manner could have a meandering form which, through time, would shift in the downstream direction as the meanders migrate. Here it becomes apparent that Carson and Lapointe's definition of the meander belt delineates the area occupied by the existing channel pattern but does not consider the future potential position of the meandering watercourse within its floodplain. To account for future downstream meander bend migration, it is advisable to delineate a meander belt that truly encompasses the lateral extent of the meander pattern on the floodplain **(Figure B3b).**

It is recognized that for a given flow and sediment regime, the rate with which a meander belt moves downstream will vary with riparian vegetation and floodplain material type. Further, it is recognized that by defining a meander belt as in **Figure B3b** that large areas of floodplain could conceivably be rendered undevelopable eventhough it is unlikely that meander bend migration or development would occupy those areas of the meander belt within a planning time frame of 200 years. Furthermore, estimation of meander position on the floodplain or indeed an estimation of channel dimensions at some point in the future is restricted by limited knowledge regarding future climate changes and precipitation patterns which could conceivably cause surface discharge to increase or decrease significantly enough to cause a morphologic channel response.

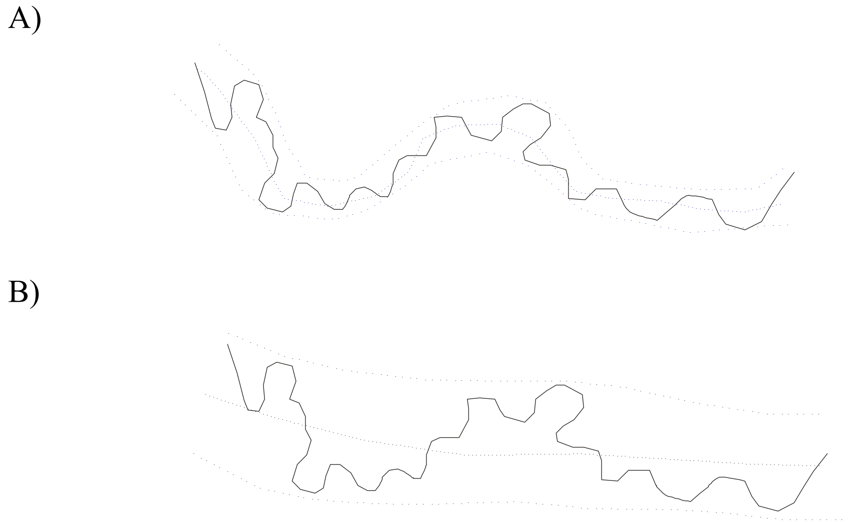

Figure B3. The belt width for an irregulary meandering watercourse could be defined around a belt axis that follows the meander pattern (A) or that follows the down-valley meander trend (B).

Empirical Relations

Various empirical formulae are presented in the literature which link belt width to discharge or to other geometric quantities. Gregory and Walling (1973) indicate that belt width is larger than meander wavelength and ranges between 14 and 20 times the bankfull channel width. Jefferson (1902) states that belt width is equivalent to 18 times the mean stream width. Through empirical analyses of Mississippi River data, Carlston (1965) related belt width (Wb) to mean annual discharge (Q_a) using the following formula:

$$Wb = 65.8\ Q_a^{0.47} \qquad r^2 = 0.96 \qquad \text{(B2)}$$

Jefferson (1902) obtained measurements of belt and channel widths for several rivers in the U.S. He distinguished between rivers that freely migrated on the floodplain and those that were incised (i.e. typical of bedrock channels, are intrenched have predominant process of incision than laterl migration). The Wb/w ratio for floodplain rivers averaged 18 and for incised rivers averaged 25 (when data not considered to represent natural conditions were removed from the data set). Bates (1939) also distinguished between floodplain and incised rivers and measured the belt and channel widths of numerous rivers (139 floodplain and 114 incised) in the U.S. using topographic maps. From these data, the average Wb/w ratio was 14.32 for floodplain rivers and 31.13 for incised rivers. This seemingly odd result can be explained by the fact that factors such as bedrock jointing (that cause preferential erosion and channel positioning within the floodplain material) and historically larger flows (which excavated the channel in which the existing channel is now situated) influence the position of the watercourse within its floodplain and would therefore be larger than expected if the same channel was situated in more erodible materials.

Using data from 194 sites, representing a variety of physiographic regions in various countries, Williams (1986) developed empirical formulae that relate belt width to other geometric variables such as wavelength (λ), radius of curvature (Rc), bankfull width (w) and channel depth (d):

$$Wb = 0.61\lambda \qquad r^2 = 0.98 \qquad 8 < \lambda < 23{,}200 \text{ m} \qquad \text{(B3)}$$
$$Wb = 2.88\ Rc \qquad r^2 = 0.96 \qquad 2.6 < Rc < 3{,}6000 \text{ m} \qquad \text{(B4)}$$

$$Wb = 4.3\ w^{1.12} \qquad r^2 = 0.92 \qquad 1.5 < w < 4{,}000 \text{ m} \qquad \text{(B5)}$$
$$Wb = 148\ d^{1.52} \qquad r^2 = 0.81 \qquad 0.03 < d < 18 \text{ m} \qquad \text{(B6)}$$

Using his database of the morphologic characteristics of Southern Ontario streams, Annable (1996a) conducted empirical analyses to examine the relation between the geometric properties and bankfull flow conditions of these streams. Based on these analyses, Annable (1996b) found that belt width ranges between 7 and 15 times bankfull discharge (Note: Annable defines belt width as the greatest lateral extent of the meander pattern that follows the trend of the valley). Annable grouped his data according to

Rosgen (1994) stream type and developed specific formulae relating meander belt width and bankfull discharge (i.e. frequency of bankfull). The streams within the TRCA jurisdiction are mainly Rosgen types C and E, although type F may also occur:

$$\text{C - type}: \quad W_b = 56.95Q_{bf}^{0.45} \quad \text{S.E.} = 0.34 \qquad \text{(B7)}$$
$$\text{E - type}: \quad W_b = 16.30Q_{bf}^{0.88} \quad \text{S.E.} = 0.29 \qquad \text{(B8)}$$
$$\text{F - type}: \quad W_b = 131.26Q_{bf}^{0.29} \quad \text{S.E.} = 0.01 \qquad \text{(B9)}$$

Newbury (July 25, 1996 – communication with TRCA) examined Annable's data and showed that belt width ranges between 5.3 and 20.3 times the channel width for Rosgen (1994) C - type streams and between 8 and 36.8 times the channel width in Rosgen E - type streams.

The streams included in Annable's database were collected in Southern Ontario. For this reason, the physiographic conditions and controls that govern the streams within the TRCA jurisdiction are more closely represented by Annable's relations than by empirical formulae derived from other data sets.

Conclusion

The lateral occupation of a river on its floodplain is of direct concern to development initiatives that seek to minimize interference with the natural processes of a river. The preceding discussions have provided background information of meander processes that are relevant to the definition of meander belt widths. Specific information regarding meander belt widths has also been presented, clarifying its definition and providing empirical relations.

In essence, the width of a meander belt represents the sum of the driving and resisting forces operative in the channel and in the floodplain. More specifically, meander belt initiation and development are driven by discharge and are limited by properties of the floodplain. For this reason, it is imperative that the flow regime, both now and in the future, be considered in any belt width delineation procedure as it has direct consequences for the lateral extent that a river will occupy on a floodplain.

Various empirical formulae relating bankfull channel width or discharge with meander belt width are presented in the literature. To estimate the belt width using these relations, bankfull channel width is multiplied by a value ranging between $4.3 < w < 20.3$, depending on the equation used (see Jefferson, 1902; Gregory and Walling, 1973; Williams, 1986; Newbury, 1996). The apparent lack of agreement in the literature concerning this relation is likely a function of site specific controls that influence meander belt width (e.g. floodplain materials), in addition to differences in the operative definition of a meander belt between researchers. These two facts reinforce the need for more than one belt width delineation procedure that account for the various relations between the river and its floodplain materials (e.g., incised).

While flow regime and floodplain properties constitute the main controls on meander migration, the process of migration (e.g., meander elongation, rotation etc.; Hooke, 1984) will also influence the space that a meandering watercourse will occupy on its floodplain. Because meander migration does not occur simultaneously along the entire length of a watercourse, some bends will grow in amplitude and irregularity while other bends will retain their position and shape. It is conceivable then that the lateral width that a watercourse occupies on its floodplain would increase as a result of local increases in meander bend amplitude, linked to bend evolution and migration (e.g., elongation; Knighton, 1998).

As noted previously, watercourses are dynamic systems that work continuously to retain or attain a state of balance with respect to the driving (e.g., hydrologic regime) and resisting forces (floodplain materials, vegetation) that influence channel form. Because of this, the observed meander configuration at any one time or place may not be the fully equilibrated form that a channel is working towards. This is especially true when substantial changes to land use and, consequently, hydrologic regime have previously occurred. When the purpose of defining a meander belt is to include existing and anticipated future meandering and migration tendencies so that any property outside of the belt will not be at risk, it is necessary to accept the notion that the existing meander configuration does not necessarily reflect a fully equilibrated state. Thus, delineation of the meander belt should allow for future evolution of a meandering planform in both the downstream and across-valley directions.

APPENDIX C

Factor Of Safety

APPENDIX C

Factor of Safety in Accurate Belt Width Delineation Procedures

The configuration (i.e., cross-section, planform, profile) of a watercourse reflects the controls and modifying influences of channel form. The dominant controls are geology and climate (i.e., discharge); modifying controls include floodplain materials, vegetation and human/animal uses. Over time, if all factors remain relatively unaltered, then the configuration that the watercourse develops will attain an equilibrium form that is in balance with the driving and resisting forces that are operative in the channel. This concept of equilibrium implies that the channel form conveys both water and sediment efficiently downstream while minimizing energy expenditure and having neither a net loss nor gain of sediment deposition or erosion. When a channel is in equilibrium, it does not imply a static position on the floodplain. Rather, an equilibrium channel may migrate and shift position on the floodplain but will have stable characteristics as it does so.

In geomorphology, there are several time-frames in which equilibrium can be evaluated (Knighton, 1998). During the *instantaneous time period* (10^{-1}), although average channel properties can be determined, they are subject to change and may not adequately account for the influence of flood events. Within the *short time scale* ($10^1 – 10^2$ yrs), the average channel form will reflect temporal variations in discharge and well-defined relationships can form between elements of channel form. In this time period, a condition of ‘steady-state’ equilibrium can exist in which the channel dimension fluctuate about a statistical average, responding to short term variations in hydrologic regime or other controlling factors of channel form. At the *medium time scale* ($10^3 – 10^4$ yrs), adjustments to internal geometry will have been made such that an equilibrium condition will have developed (i.e., flow regime is able to transport the sediment supply). In this time scale, a condition of dynamic equilibrium or dynamic meta-stable equilibrium may exist where the channel has adjusted to existing conditions or to alterations in driving or resisting forces that influence its configuration. Both the short and medium time scales are significant since the channel is able to adjust to some trends of the flow and sediment regimes.

Inherent in the notion of steady-state equilibrium, is that the channel will make adjustments in form during short time periods but that, over the long term, the channel fluctuates about an average form. When changes in the driving or resisting forces occur, then the channel will make adjustments but return to its average equilibrium form within a relatively short period of time. If the magnitude or rate at which a change in the driving or resisting force occurs is greater than the ability of the channel to absorb, then the channel will make adjustments and establish an equilibrium form that will differs from the initial equilibrium condition.

When a change in driving or resisting forces has occurred, then it can be inferred that the watercourse is adjusting to these changes in some manner. In the Greater Toronto Area, the most dramatic change in driving forces has occurred in conjunction with changes in hydrologic regime. These changes include those associated with the initial clearing of land from forest to agriculture (European settlement) and the change from agriculture to urban setting. Both of these changes also have implications for the sediment supply that is delivered to the channel. The response of watercourses to urbanization has been documented to span at least several decades (e.g., 30 – 60 yrs or longer).

Although the concept of equilibrium may be understood, there is not yet a well-developed approach to ascertain whether a watercourse or reach has attained an equilibrium form. View of a watercourse at any one time provides a snap shot but does not place it in the context of the natural variability that is inherent in the system or of long-term changes such as those associated with the establishment of new equilibrium conditions. Although a review of historic air photos provides some insight into the relative equilibrium condition of the watercourse, it is necessarily limited since it provides only two dimensional snap-shots in time.

When delineating a meander belt and projecting what the width of the meander belt might be in the future, various assumptions need to be made. Since the purpose of delineating a meander belt is to identify the area that the watercourse can reasonably be expected to occupy in the future such that there is little risk to life or property, it is necessary to account for future processes and potential channel position. Specifically, when the meander belt is used for planning purposes and its width is based only on existing characteristics of the reach, then at some point in the future, life or property may become at risk. It is necessary therefore to make allowance for future channel migration and adjustments to occur.

In **Procedures 2 and 3**, the meander belt was quantified by allowing for potential migration and belt axis shifting within a projected 100-year period. An additional factor of safety was also incorporated into **Procedures 2 and 3** (for situation where the meander belt is > 50 m wide). The rationale for the determination of the future meander belt equations are outlined below.

Procedure 2: When no change in hydrology is anticipated

When meander belt is < 50 m

Eq. 3. Final Belt Width = belt width + channel width + 100 year migration distance + 100 year shift in belt axis

This method, when no change in hydrologic regime is anticipated, takes into account the historic migration rate and shift in meander belt. Neither of these (i.e., migration rate, axis shift) are expected to change in the future with the assumption that no change in driving or controlling factors are anticipated in the reach.

When meander belt is > 50 m

Eq. 4. Final Belt Width = (belt width + channel width) * 1.10 + 100 year shift in belt axis

Equation 4 differs from Equation 3 since the rate of migration (of the belt width defining meanders) typical of wider channels tends to be less than in smaller watercourses (i.e., typically having meander belts that are < 50 m wide). Smaller watercourses tend to be controlled by local factors (e.g., floodplain vegetation) and exhibit more dynamic shifting on the floodplain than larger watercourses. The factor 1.10 appeared to be a reasonable value to represent the rate of channel shifting based on the average migration rates for belt width defining meanders (i.e., in the examples tested, the migration rate of the outside meander bends was approximately 10% of the meander belt width). In situations where there is visible evidence of active channel migration along the outside meander bends, then it is more appropriate to apply the method defined by Equation 3 for the > 50 m wide reach.

Procedure 3: When a change in hydrologic regime is anticipated

When the belt width is < 50 m

Eq. 5. Final belt width = (Belt width + channel width) * 1.05 + D + E

The only difference between Equations 3 and 5 is the incorporation of a safety factor (i.e., 1.05). This value is intended to account for the influence of a change in hydrologic regime on the watercourse. The rationale for a safety factor of 1.05 is based on a conservative estimate pertaining to the anticipated increase in migration rates that could occur in conjunction with a change in hydrologic regime.

When the belt width is > 50 m

Eq. 6. Final belt width = (Belt width + channel width) * 1.20 + E

For the situation in which a change in hydrologic regime is anticipated, the safety factor (i.e., 1.20) has been increased from the scenario described in Eq. 4. The increase is based on the understanding that a change in hydrologic regime will cause a response in channel form and would increase existing migration rates. Although the magnitude of the increase will vary for each setting and situation, the 1.2 safety factor was considered to be suitable, based on a review of historic air photos for reaches in which the hydrologic regime had been recently (i.e., within last 30 years) been altered.