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Interpretation guide of natural geographic features from ETM+ Landsat imagery and aerial photography: permanent water

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Introduction

The purpose of this project is to create a visual interpretative guide to the natural geographical entities in the geospatial database (GDB) using Landsat7 ETM+ imagery and aerial photography. The methodology and information fact sheet were developed by Provencher and Dubois (2004a), and the application of this procedure to a test case has already garnered a consensus among the staff of CTI at Sherbrooke (Provencher and Dubois (2004b). The meanings of the sections of the fact sheets are explained in the appendix.

The eight natural entities in the GDB (Centre for Topographic Information, 2004) fall under eight themes that are grouped into three domains: hydrography, landforms, and vegetation (Table 1). In practice, for interpretive purposes they are often subdivided further and represented by 17 fact sheets.

N.B.: Elaboration of the illustrative examples and potential elements of confusion was constrained by the limited time allocated to this guide. It is recommended that they be supplemented as other cases are documented, especially from Landsat ETM+ imagery.

Table 1: Hierarchy of natural geographical entities

Domain	**Theme**	**Sub-theme**	**GDB entity**	***Fact sheet***
Hydrography	Watercourse	Perennial watercourse	Permanent water	*Permanent water*
		Alluvium	Intermittent water	*Intermittent water*
		Waterfall	Water disturbance	*Waterfalls and rapids*
		Rapids	Water disturbance	*Waterfalls and rapids*
	Waterbody	Perennial freshwater body	Permanent water	*Permanent water*
		Alluvium, rocky surface	Intermittent water	*Intermittent water*
		Saltwater	Permanent water	*Permanent water*
		Alluvium, rocky surface (tidal flat)	Intermittent water	*Intermittent water*
		Reef	Water disturbance	*Reef*
	Wetland	Tundra pond	Saturated soil	*Tundra ponds*
		Palsa bog	Saturated soil	*Palsa bog*
		Marsh, swamp, and uniform peat bog (wetland)	Saturated soil	*Wetlands (marshes and swamps, peat bogs*
		String bog	Saturated soil	*Wetlands (string bog)*
Landforms	Glacial landform	Glacial debris	Landform	*Glacial debris*
		Esker	Landform	*Esker*
		Moraine	Landform	*Moraine*
		Glacier, glacial ice cap, and ice shelf	Permanent snow and ice	*Permanent snow and ice*
	Periglacial landform	Polygonal soil	Landform	*Tundra polygon*
		Pingo	Landform	*Pingo*
	Littoral landform	Barrier beach and spit	Landform (sand)	*Barrier beach and spit*
	Eolian landform	Dunes	Landform (sand)	*Dunes*
Vegetation	Wooded region		Wooded region	*Wooded region*

1- Name of the entity

Permanent water

2- Hierarchy

Hydrography – watercourse or waterbody – permanent water

3- Definitions

3.1- Permanent water

A watercourse or watercourse segment, or waterbody or waterbody segment, that is perennial and independent of seasonal or annual variations in runoff, rainfall, or tides. It is limited by the mean low-water level. In a fluvial environment, this limit should generally correspond to the low-flow channel, but it may correspond to the base-flow channel in some drought-prone areas (cf. Section 5.2.3, Figure 9).

3.2- Watercourse

A linear, permanent or intermittent, naturally occurring formation for draining water, occasionally partially subterranean, that collects runoff in a terrestrial environment. Sometimes a watercourse, or a part of a watercourse, is channelized.

3.2.1- Types of watercourse

All watercourses consist of at least one channel. The **channel** is the area between the two banks of a watercourse that is usually under water. This term is often used to distinguish between the various branches of a watercourse, e.g. in a floodplain or a delta.

A watercourse may have different names depending on its dimensions, hierarchical rank, and certain other physical characteristics: estuary, river, creek, canal, ditch (**Figure 1**).

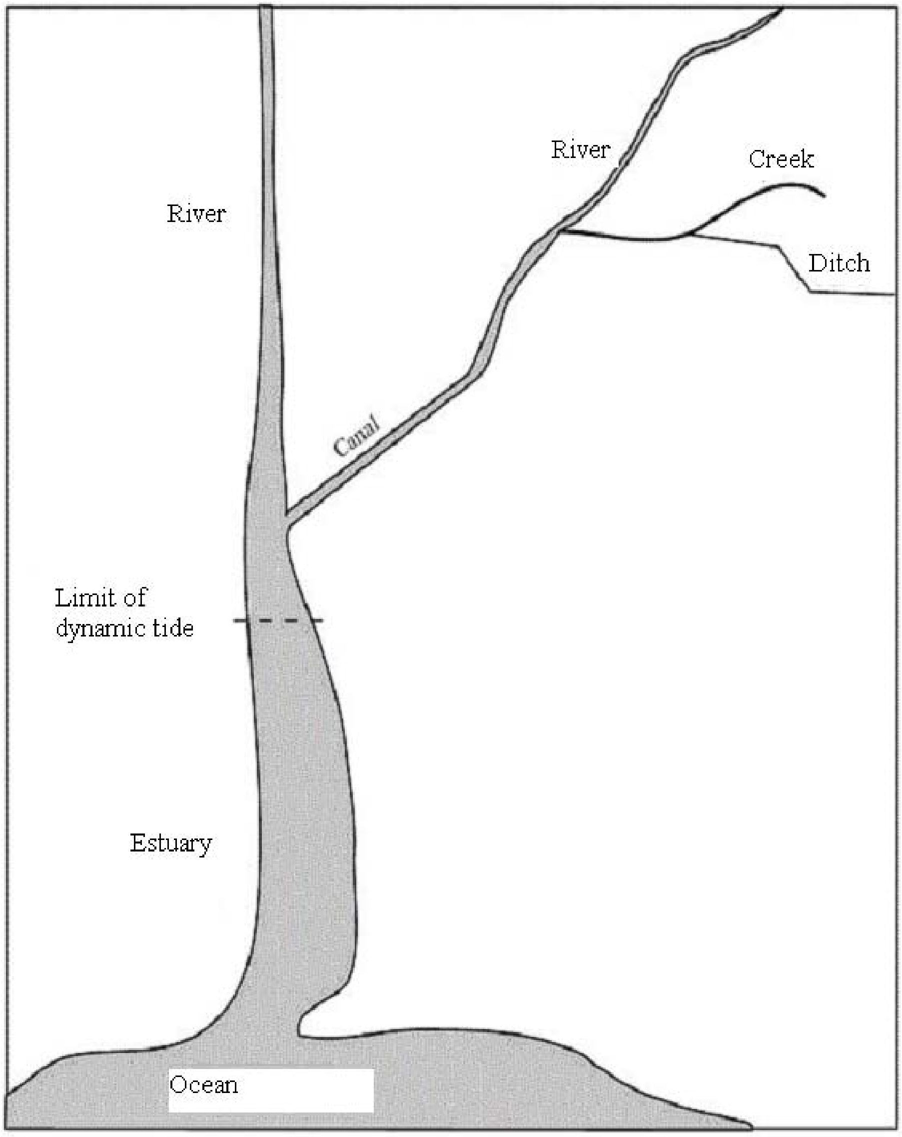


Figure 1 :Types of watercourses

Estuary: the mouth of a permanent river discharging into a sea, an ocean, or another estuary and affected by tides (saline or brackish water) or river tides (freshwater from the watercourse that is pushed upstream as the tide rises). Estuaries are characterized by a high degree of sedimentation, especially near their mouths. Some very large estuaries are considered waterbodies (e.g. the St. Lawrence Estuary).

River: a first-rank watercourse, of large or intermediate size (10+ km), that is usually permanent but may be intermittent in arid or karstic regions. It collects water from streams and other rivers and carries it to another river or a large waterbody.

Creek: a short (1 to 10 km), permanent or intermittent, second-rank watercourse that collects water from springs and rills and carries it to rivers. In Québec, the Commission de toponymie du Québec designates certain creeks in agricultural areas as **watercourses**.

Canal: an artificial watercourse built for drainage or to link two natural watercourses or waterbodies. Canals are often natural watercourses that have been channelized and diked.

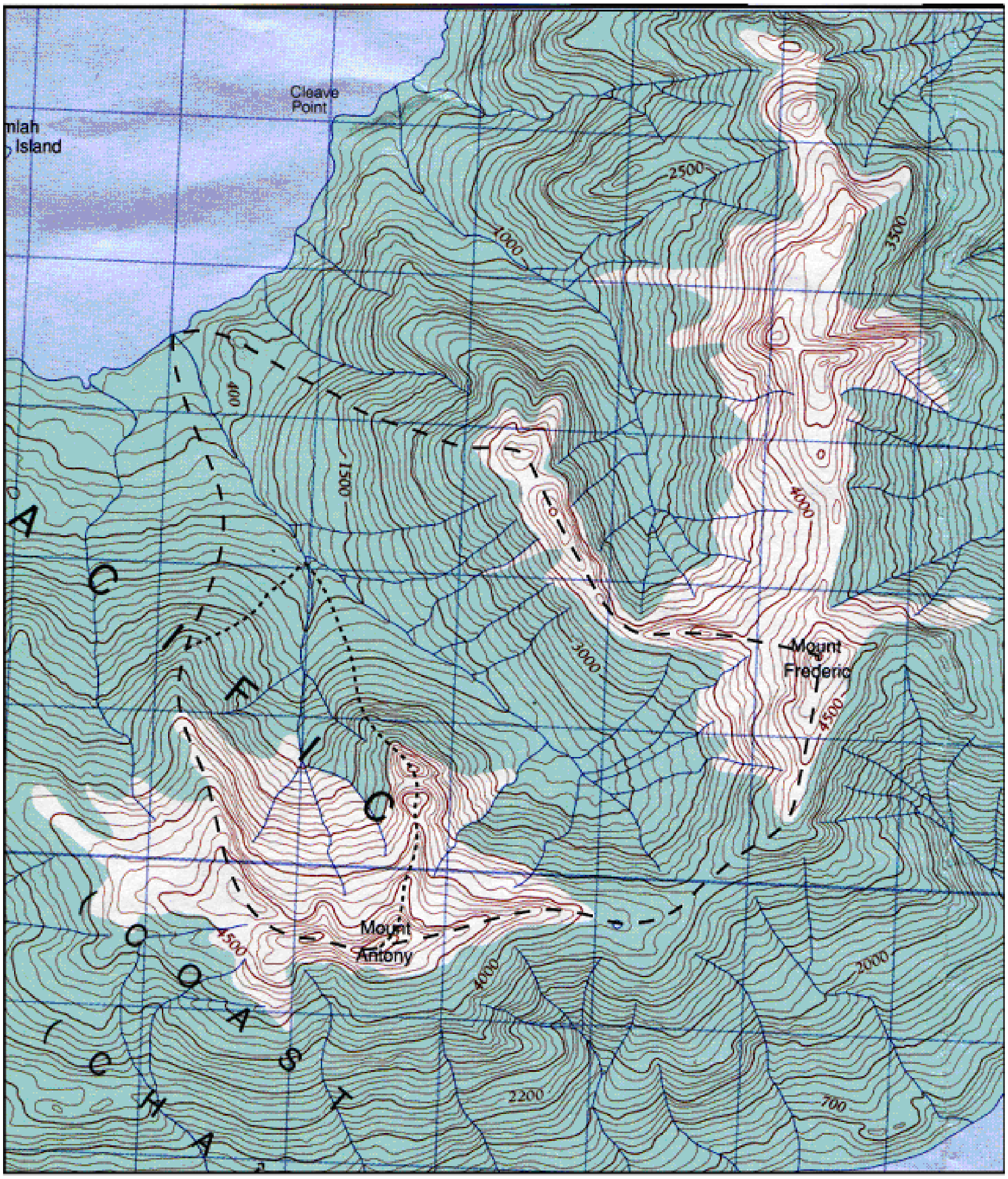
Ditch: an artificial, usually intermittent, watercourse. Ditches are very short (generally less than one km) and serve to drain land for urban or agricultural uses. Only the largest ditches are marked on topographic maps.

3.2.2- Drainage basin

All watercourses drain some area of land, called a **drainage basin**, which is separated from neighbouring drainage basins by a **watershed**. Consequently, any drainage basin can be partitioned into numerous sub-basins, the limit being determined by the smallest mapped watercourse. A drainage basin with its sub-basins is illustrated in Figure 2.

Starting at the mouth of the watercourse, the watershed runs along the high points of the **interfluve**, which is the territory between the watercourse and its neighbour on each side. When a digital elevation model is available, using contour lines to perform an assessment, even cursory, of the delimitation between drainage basins may prevent errors when plotting hydrographic networks.

In some flat areas watercourses may switch between drainage basins seasonally, as a function of stream discharge. This is the case, for example, for many Nunavik watercourses on the Québec-Labrador border.



Source : carte 92L/9 (Minstrel Island, C.-B.)

– – – – limite du bassin versant
----------- limite d'un sous-bassin versant

Figure 2 :Example of two drainage basin limits

3.2.3- Hydrographic network

All watercourses belong to a hydrographic network—a linear water drainage system that is usually dendritic or structured—carrying the runoff of a drainage basin. Except under certain circumstances we shall examine later, all watercourses in a hydrographic network must be able to flow without interruption from their **headwaters** (sources) to their **mouths** (outlets).

There are various **types of hydrographic networks** (Gagnon, 1974). The principal hydrographic networks are illustrated schematically in Figure 3 and depicted photographically in Figure 4. Within a given drainage basin, watercourses usually adhere to one of these types, but several may be present when the geology or geomorphology is variable.

Dendritic hydrographic network

A set of branching watercourses with a tree-like structure. This is the most common type in environments characterized by uniform erosion (e.g. the Appalachian Region).

Angular hydrographic network

Watercourses with a dendritic structure and with the further characteristic that they intersect at right angles. This is the most common type in environments characterized by fractured rocks (e.g. the Canadian Shield).

Parallel hydrographic network

A set of parallel and straight watercourses flowing over rocky surfaces or impermeable, uniform, and homogeneous unconsolidated deposits with a constant and unidirectional gradient. This is the most common type in coastal plains (e.g. south-western James Bay).

Annular hydrographic network

A set of watercourses laid out in rings, often with many short secondary perpendicular watercourses. This is the most common type in environments characterized by dome-shaped geological structures where rocks with varying resistance to erosion form concentric rings (e.g. Mount Megantic).

Radial hydrographic network

A set of watercourses diverging from a central point. This is the most common network among circular or cone-shaped mountains.

Dichotomous hydrographic network

This is, in fact, a reversed dendritic hydrographic network. Rather than gathering the water into a collector, the branches carry water away from the main channel. This is the type of network found in deltas and alluvial fans (e.g. Mackenzie River delta).

Unordered hydrographic network

A set of watercourses and waterbodies with varying orientations located in rocky environments and impermeable glacial till that is topographically uniform (e.g. north-central Anticosti Island),

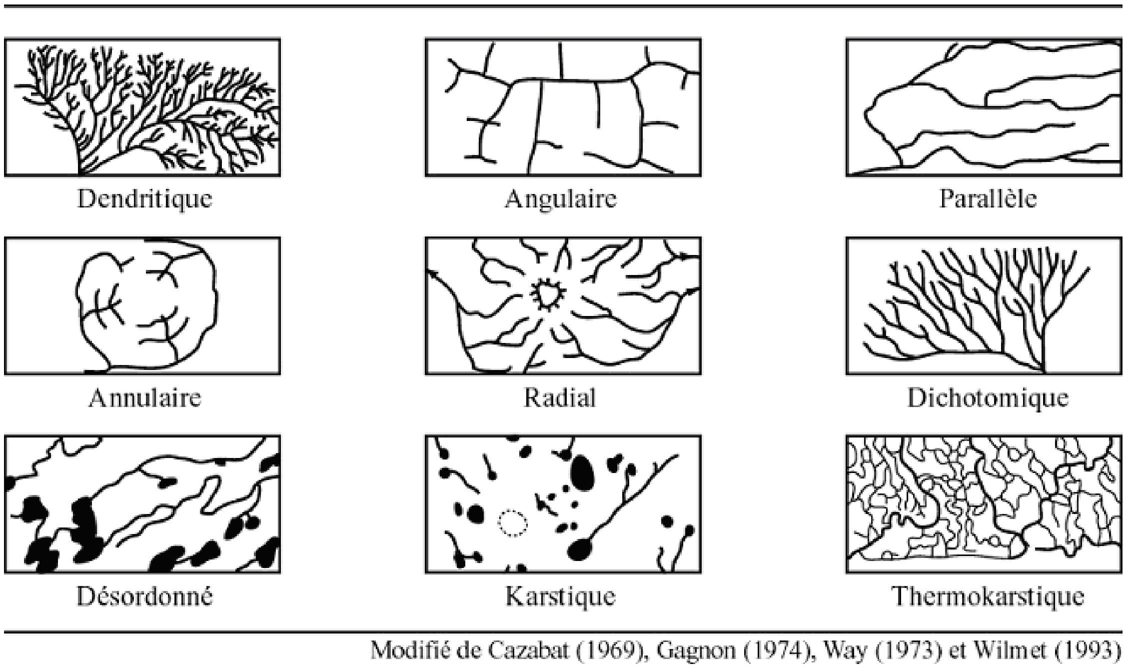
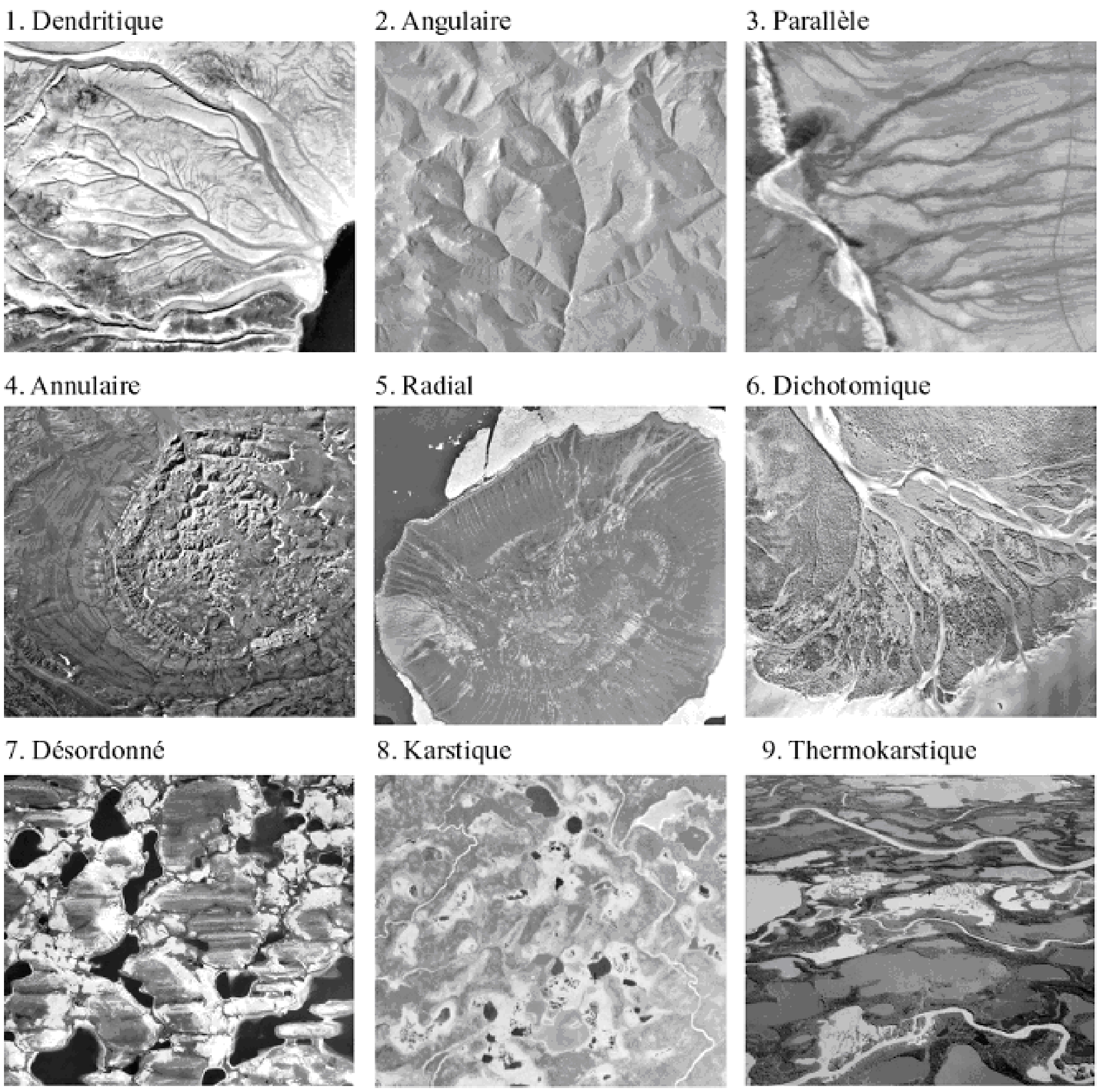


Figure 3 :Main hydrographical network types



Photos : A12147 (8), A13752 (28), A16193 (91), A16748 (130), A5020 (88R), A13440 (388) et Lab-SP-18 (128), A11531 (410), T428c (161) du Ministère de l'énergie, des mines et des ressources du Canada

Modifié de Provencher et Dubois (en prép.)

Figure 4 : Pictures of main hydrographical network tyes

Karstic hydrographic network

A set of watercourses and small waterbodies with varying orientations overlying limestone bedrock (c.f. *intermittent water* fact sheet for the distribution of karst in Canada). A unique feature of this network is enclosed depressions—some of which are filled with water—created by the dissolving of limestone, and watercourses that partially run underground (along a gradient) and so cannot be seen from the surface (e.g. north-central Anticosti Island).

Regardless of the hydrographic network, in regions that are only slightly karstic a small proportion of the watercourses may lie underground while the network as a whole does not reveal karstic features.

Thermokarstic hydrographic network

Specific to periglacial regions (cf. Section 5.2.1), the thermokarstic network is characterized by many small waterbodies that are created by thawing permafrost and linked by short, sinuous watercourse segments with varying orientations. The name thermokarstic reflects the phenomenon of thawing, which yields a relief similar to that of dissolving limestone (e.g. permafrost regions of the Canadian north).

3.3- Waterbody

A topographical depression of variable size that is filled with water. It generally sets the base level (outlet) for one or several waterbodies.

Waterbodies have different names that reflect their size and certain physical characteristics: ocean, sea, lake, pond, tundra pond, lagoon.

Ocean or **sea**

A vast waterbody (over 100 km in diameter) that provides the base level for many rivers.

Lake

A large freshwater body (from 1 to over 100 km in diameter that is more or less round or elongated, depending on the relief, and surrounded by land. This name is also occasionally applied to saline or brackish waterbodies in rocky environments that are linked to an ocean, sea, or estuary by a narrow inlet. Usually, lakes are closed waterbodies having a watercourse as outlet, but some may simply be a widening in a watercourse. Lakes are generally natural formations, but a few are manmade or have water levels that are raised or controlled by dams to regulate the flow of water, create reservoirs of drinking water, or generate hydroelectricity.

Pond

A small body of fresh water (less than one km in diameter) that is more or less circular and surrounded by land. Many ponds are artificial, being used for agriculture, aquaculture, recreation, or landscaping. Some are located at the bottom of sand or gravel pits or abandoned mines. Others, frequently more transient, are created by beavers. The beaver is present throughout the south of Canada, including boreal regions.

Tundra ponds

Shallow, round waterbodies of a small size (from several metres to several hundred metres in diameter) resulting from the differential melting of permafrost (cf. the *tundra ponds* fact sheet).

Lagoon

An elongated (100 m to 100 km) saline or brackish waterbody between the mainland and a sandy or gravely offshore bar that is breached by one or several inlets allowing the inflow and outflow of tides. Their altitude is thus that of the adjacent waterbody. In Atlantic Canada, lagoons are sometimes called **barachois**.

4- Summary table of elements of identification

Table 2: Overview of the elements of identification of narrow permanent watercourses

Shape	View from top: linear and sinuous
Dimensions	Length: decametres to kilometres Width: metres to kilometres
Topographic position	Valley bottom
Drainage	Not applicable
Vegetation	Generally absent Sometimes aquatic vegetation on the bank Often partially or totally obscured by the canopy
Emplacement process	Headward fluvial erosion
State	All
Spatio-temporal variations	Low-flow channel generally stable except in meander belts, floodplains, and deltas Seasonal variations in water levels
Environment	All environments, except deserts
Identification on imagery	Band 4 (IR): water black
Identification with B/W aerial photography	Hue dark grey to black Smooth texture
Elements of confusion	High turbidity zones, marshes, vegetation, specular reflection, river ice, water level, loss (karst)

Table 3: Overview of the elements of identification of permanent waterbodies (including broad watercourses)

Shape	View from top: Variable surface geometry, simple or complex shape
Dimensions	Diameter: decametres to kilometres
Topographic position	Topographic depression or valley bottom
Drainage	Not applicable
Vegetation	Generally absent Sometimes zones of aquatic vegetation Sometimes shores obscured by canopy
Emplacement process	Depression of tectonic, glacial, periglacial, karstic, fluvial, etc. origin
State	All
Spatio-temporal variations	Stable Sometimes seasonal or multi-year variations in water levels
Environment	All environments, except deserts Waterbodies more common in northern regions
Identification on imagery	Band 4 (IR): water black
Identification with B/W aerial photography	Hue dark grey to black Smooth texture
Elements of confusion	Intermittent water, high turbidity, aquatic vegetation, vegetation, marshes and swamps, beaver ponds, ice, frazil ice, agitation of the water, specular and cloud reflection, water level, shade.

5- Characteristics

5.1- Specific to the entity

5.1.1- Shape

A) Watercourse

In addition to the shapes of hydrographic networks (Section 3.2.2-), watercourses themselves may vary in shape along their course (Bravard and Petit, 2000). The principles are illustrated in **Figure 5**, and examples are provided in Section7.1- .

Most watercourses have a single channel that is either **straight** or **sinuous**, especially in the upper reaches of their drainage basins. This is were river erosion is most active and apparent. All other shapes only appear in specific segments of the watercourse: They will be examined in detail to assist in their identification.

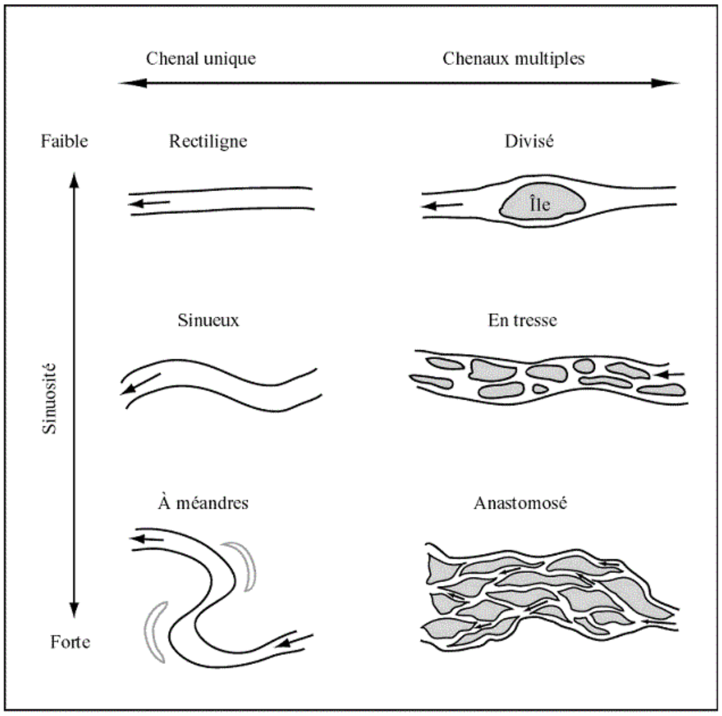
Meanders are typically found in areas where the relief is flat (plains or plateaus). The lateral displacement of the riverbed creates ever-deeper loops which are eventually cut off, leaving blind channels in the abandoned segments. These crescent shaped segments, called oxbows, may be filled with water, in which case they are called oxbow lakes. In particularly complex cases it is necessary to carefully distinguish between the main channel of a permanent watercourse and the abandoned, or intermittent, channels (cf. the *intermittent water* fact sheet).

The simplest case of a watercourse with multiple channels is one that is **split** around an island. This is a common phenomenon that can be found in any watercourse type and on any stretch of it.

In more complex cases, such as **braided** or **anastomosed** channels, identifying the channels of permanent water may prove more challenging. These formations appear in segments of the watercourse with high sedimentation. The braided shape is most common upstream from estuaries or downstream from sudden changes in gradient, where the pace of the flow is abruptly slowed. The anastomosed shape is characteristic of zones of intense sedimentation, such as downstream from glaciers in glacial outwash plains.

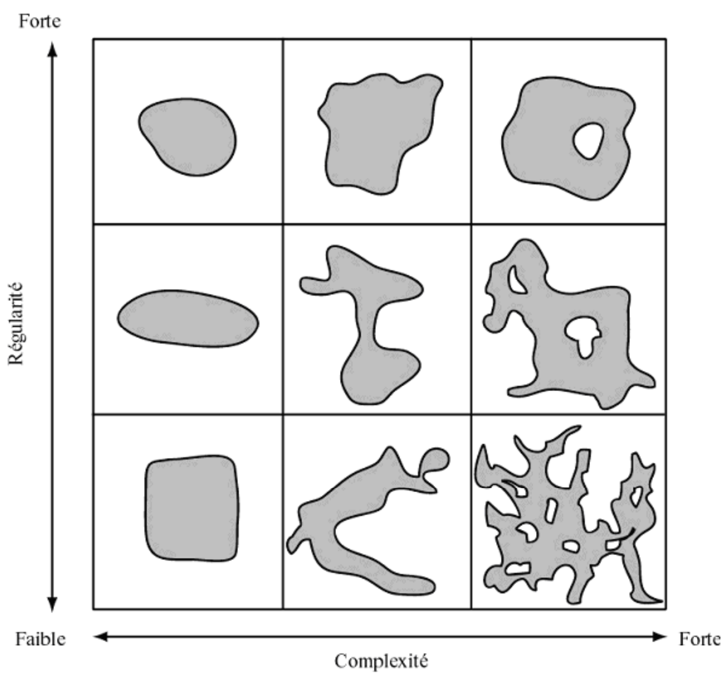
B) Waterbodies

The shapes of waterbodies vary as a function of their smoothness and complexity (Figure 6). With a few exceptions, such as crater lakes or karst ponds, waterbodies with simple shapes are usually situated on unconsolidated deposits. Conversely, those with a more complex geometry are typical of rocky substrata environments.



Modifié de Bravard et Petit (2000, p. 112)

Figure 5 : Main watercourse shapes in relation to bend and number of chanels



Modifié de Provencher et Thibault (1976, p. 5)

Figure 6 : Main waterbody shapes

5.1.2- Dimensions

A) Watercourse

Length: from several hundreds of metres for ditches and creeks to several hundreds of kilometres for rivers (cf. Section3.2.1-).

Width: from about one metre for ditches and creeks to several kilometres for rivers and estuaries.

B) Waterbody

Diameter: from several decametres for ponds to thousands of kilometres for oceans (cf. Section3.3-).

5.1.3- Topographic position

Watercourses are only found in valley bottoms, regardless of the size of the valley. In flat areas, their courses can be plotted from images. In rougher terrain, this can be supplemented by examining contour lines to establish the direction of the slope. Thus, it is recommended to always compare the plot of the watercourse with contour lines from a topographic map.

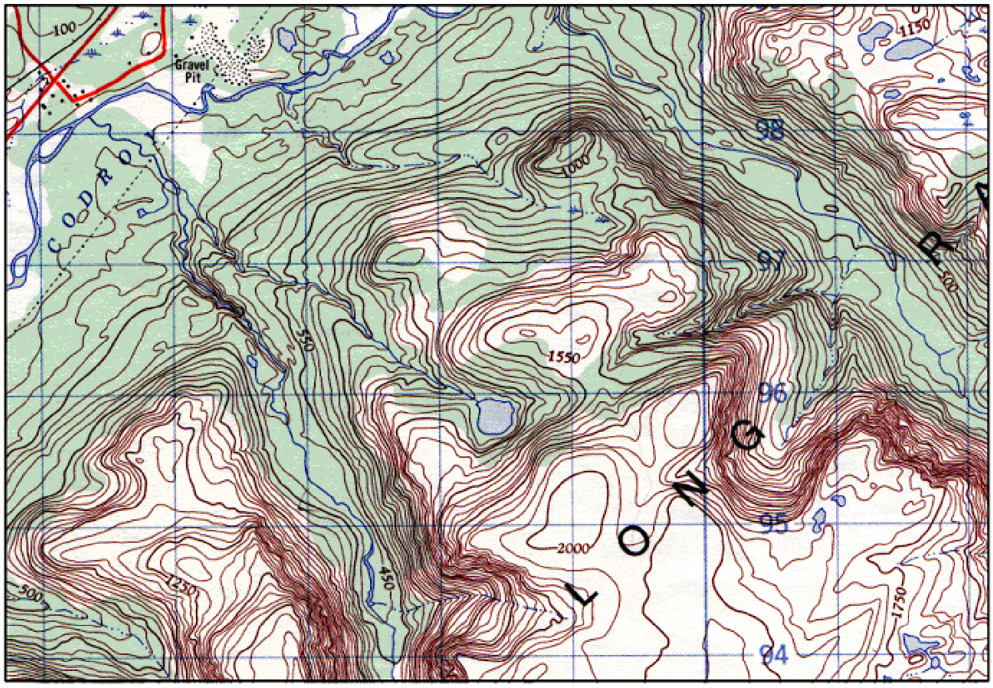
Waterbodies occur in any topographic position, but always in depressions. Unless retained by a natural or manmade dam, they are generally found at the lowest point of a region. Oceans are always near sea level and, in Canada, all seas are, too.

5.1.4- Drainage

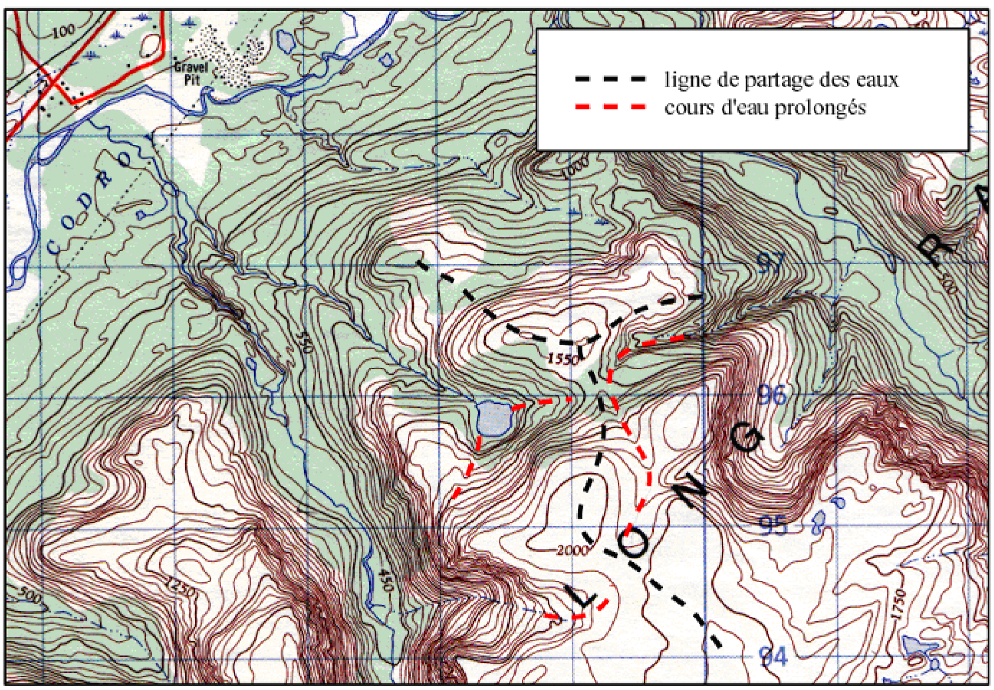
This criterion is not applicable.

5.1.5- Vegetation

Watercourses and **waterbodies** are usually devoid of visible vegetation. However, zones of aquatic vegetation (water plants and algae) may be found in shallow water, usually near the banks. The presence and density of vegetation may vary over the course of the growing season. These zones are considered part of the watercourse or waterbody unless they are large enough to qualify as wetlands (cf. the *marshes, swamps, and bogs*, *peat bogs*, *tundra ponds*, and *palsa bogs* fact sheets).



A) Carte topographique 11 O/14 (Codroy, Terre-Neuve)



B) Prolongement possible des cours d'eau permanents ou intermittents jusque vers la ligne de partage des eaux

Figure 7 : Example of information supplied by contour lines in determining watercourse location

In wooded environments watercourses may be masked by the canopy. Conversely, riparian vegetation (e.g. alders) growing in columns along the shore may sometimes help to locate them.

5.2- Relative to the entity's dynamics

5.2.1- Emplacement process

A) Watercourse

Watercourses are first and foremost natural components of the earth's hydrological system. They collect rainwater and transfer water from springs into low-lying areas. Except in some desert regions, the endpoint of the system is always a waterbody, to which it also carries sediments picked up by all agents of soil erosion. On the other hand, some watercourses or parts of watercourses have been modified by human activity, usually to straighten or dike them. Finally, some are completely manmade, such as various types of canals and drainage ditches.

B) Waterbody

The origins of waterbodies are more diverse (Pearl, 1976–1978). The forces that give birth to them may be tectonic or structural, craterous or meteoric, glacial, periglacial, littoral, eolian, fluvial, paludal, anthropogenic, or biological.

A majority of waterbodies are of **tectonic origins** and result from faulting in the earth's crust. These faults may be immense, as in the case of oceans, seas, and some great lakes, or of more modest dimensions, as in the case of most lakes. Lakes thus formed have elongated shapes that correspond to the faults or fractures, or highly irregular shapes with sharp angles. They are always associated with outcrops of the rocky substrate.

Sometimes round lakes occur in **volcanic craters** or in depressions left by **meteor impacts**. They are typically deep and have steep slopes.

The origins of many lakes and ponds are **glacial**. They may be associated with over deepening or glacial sedimentation. The former, which are usually larger, are found in many elongated depressions having the same orientation as the progression of the glaciers. They lie in the clefts gouged out by many glaciers that were active during the most recent geological period, the Quaternary, which encompasses the past several million years. Other, smaller, moraine lakes are trapped behind dams formed by moraine ridges (sedimentary formations bordering glaciers), depressions in glacial till left by receding glaciers, or even ice dams beside or on top of current glaciers.

In Canada, the **periglacial** region begins intermittently somewhere near the 52nd parallel, becoming continuous north of the 55th parallel, except in the mountainous regions of the west where it extends farther south. The extent of this region can be readily grasped from looking at the 1995 permafrost map in *The Atlas of Canada* (http://atlas.gc.ca). In the flat areas of this region many shallow small lakes and ponds occupy the depressions left by differential thawing of the ice in the soil (the permafrost) (cf. Hamelin and Cook, 1967). This is where we find tundra ponds (cf. the *tundra ponds* fact sheet).

In the **littoral** zone very large waterbodies can form behind sandy or gravely barrier beaches and spits. These lagoons are generally shallow and connected to the sea by inlets through which tidal currents flow. Other waterbodies that are narrow but very long, and that are fed by groundwater seepage, can persist between emergent barrier beaches.

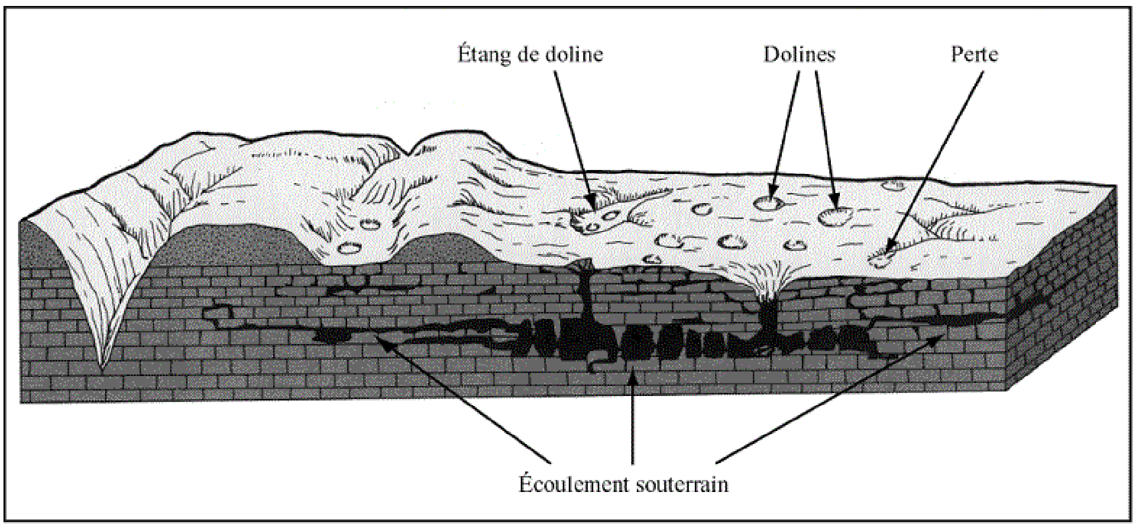
Zones of dunes in the sandy littoral may harbour small lakes or ponds of **eolian** origin. They occupy the bottoms of blowout basins that were overdeepened during the fall of the water table.

In **fluvial** environments we find small oxbow lakes, actually ponds, in abandoned meanders. Other lakes, which can be very large, are formed by the widening of watercourses.

In environments characterized by organic sedimentation, or **paludal deposits**, we find small waterbodies, usually ponds, that either individually or as a group are remnants of a much larger waterbody that has eutrophied, i.e. progressively succumbed to encroachment from the edge by aquatic vegetation to become a bog.

In **karst**, small lakes or, more commonly, ponds form in depressions left by dissolved limestone or the collapse of underground cavities. These are called dolines or sinkholes (Salomon, 2000) (**Figure 8**). The *intermittent water* fact sheet contains a map with the distribution of karst in Canada. Clusters of dolines make up a karst valley which, being larger, may contain a bigger lake than the sinkholes. These lakes and ponds may be intermittent or have fluctuating water levels (cf. the *intermittent water* fact sheet).

Some lakes, and especially ponds, are **anthropomorphic** creations with various purposes to which we alluded in section 3.3- . Ponds may also have **biological** origins, resulting from the efforts of beavers, which frequently dam small watercourses to build their own habitat. These ponds are generally short-lived, turning into intermittent waterbodies (cf. *intermittent water* fact sheet) or wetlands (cf. *marshes, swamps, and bogs* fact sheet).



Modifié de Leet *et al.* (1982, p. 300)

Figure 8 : Geomorphology of a karst environment

5.2.2- State

Permanent watercourses and waterbodies exist in all environments except arid zones. As previously mentioned, they form naturally, but some have been modified by human activity. Thus, we find channelized streambeds and embanked rivers, lakes, and seacoasts. New natural or manmade lakes and ponds may also appear while others vanish.

5.2.3- Spatio-temporal variations

Permanent watercourses are constituted of a base-flow channel, which is always under water, a low-flow channel that is usually under water, and a high-flow channel that is only submerged during high waters. Plots of watercourses on maps should represent their low-flow channels. In certain situations, however, the base-flow channel assumes the role of the low-flow channel (**Figure 9**). This bed does not change on a seasonal or annual basis, though in certain regions it may dry out after several years of drought. In flat regions with high sedimentation, such as floodplains, deltas, or glacial outwash plains (downstream from current glaciers), it may also shift. Permanent watercourses may appear or disappear over millennia, but that falls outside of the scope of this guide.

Natural changes to large bodies of water (oceans, seas, lakes) only occur over thousands of years. Conversely, humans may create or eliminate lakes. In some milieus (arid, karstic, periglacial), small waterbodies (lakes and ponds) may appear or disappear rapidly.

Surfaces of watercourses or waterbodies, or of some parts of watercourses or waterbodies, can vary in appearance over time owing to: (1) rainfall or seasonal events, (2) the phenological or submersion state of aquatic vegetation, (3) high turbidity, i.e. the content in suspended matter (sediments or organic matter), (4) agitation by wind (small ripples or wave surges), and (5) a blanket of frazil ice or sheet ice, or ice beneath a layer of snow. All of these will cause their appearance on imagery and aerial photography to vary.

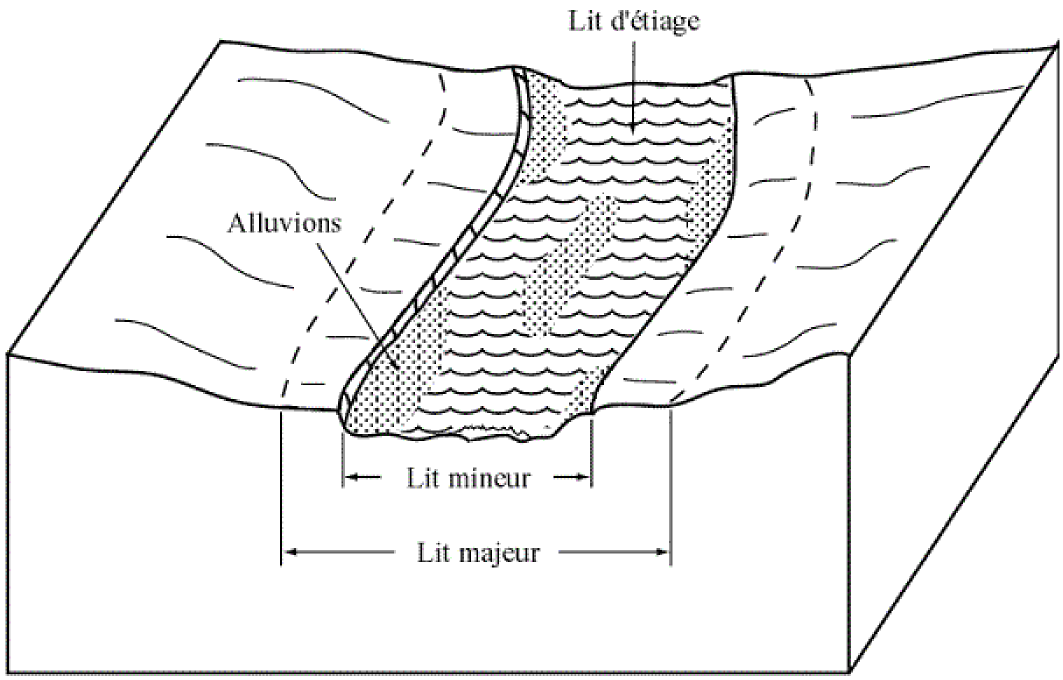


Figure 9 : Illustration of different watercourse channels

5.3- Relative to the environment

Watercourses and waterbodies are found in all environments, except arid zones, so there is no specific environmental element that is useful to help with their identification.

6- Optimal conditions for identification

In general, band 4 (IR) should be used with ETM+ images, since water stands out because it absorbs the waves in this band. When the water is calm its surface appears black. However, the appearance of the water's surface in this band may be modified by several factors, the main ones being:

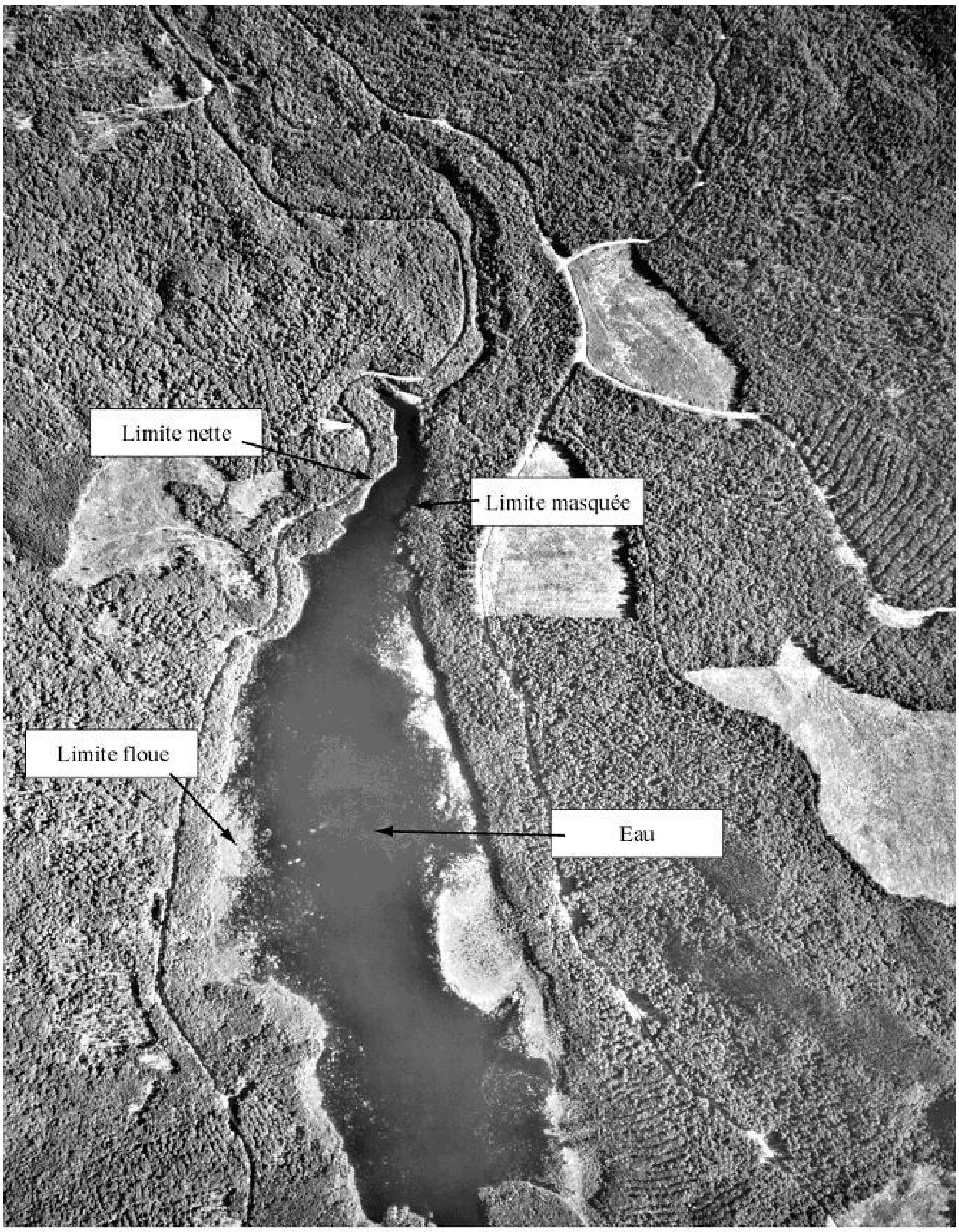
- high turbidity (suspended mineral or organic matter);
- the presence of emergent or floating aquatic vegetation;
- a blanket of frazil ice or sheet ice, or ice beneath a layer of snow;
- agitation of the water (ripples or waves) creating a reflection;
- specular and cloud reflection;
- shade.

In order to evaluate the risk of confusion created by these factors, the analyst must have a sufficiently detailed understanding of the climatic and biophysical conditions in the area under study. These sources of confusion will be discussed in Section 9- .

On B/W aerial photography, water surfaces appear dark grey or black owing to their poor reflectivity. This factor, along with the fact that it also captures shallow expanses of water and hence portrays a wide range of shades of grey, must be accounted for.

7- Examples

7.1- Presence and limit of permanent water



Source : photo HMQ98-131(85), échelle originale 1 : 15 000, carte 21 E/07, 45° 21' N - 70° 37' O, Massachusetts Bog, Maine, du 19-07-1998

Figure 10 : Example of different permanent water limits

Source : photo de J.-M. Dubois, ouest du mont Mégantic (Québec) no 72-MM-10

Figure 11 : Example of a permanent watercourse completely masked by tree canopy

7.2- Watercourse shapes

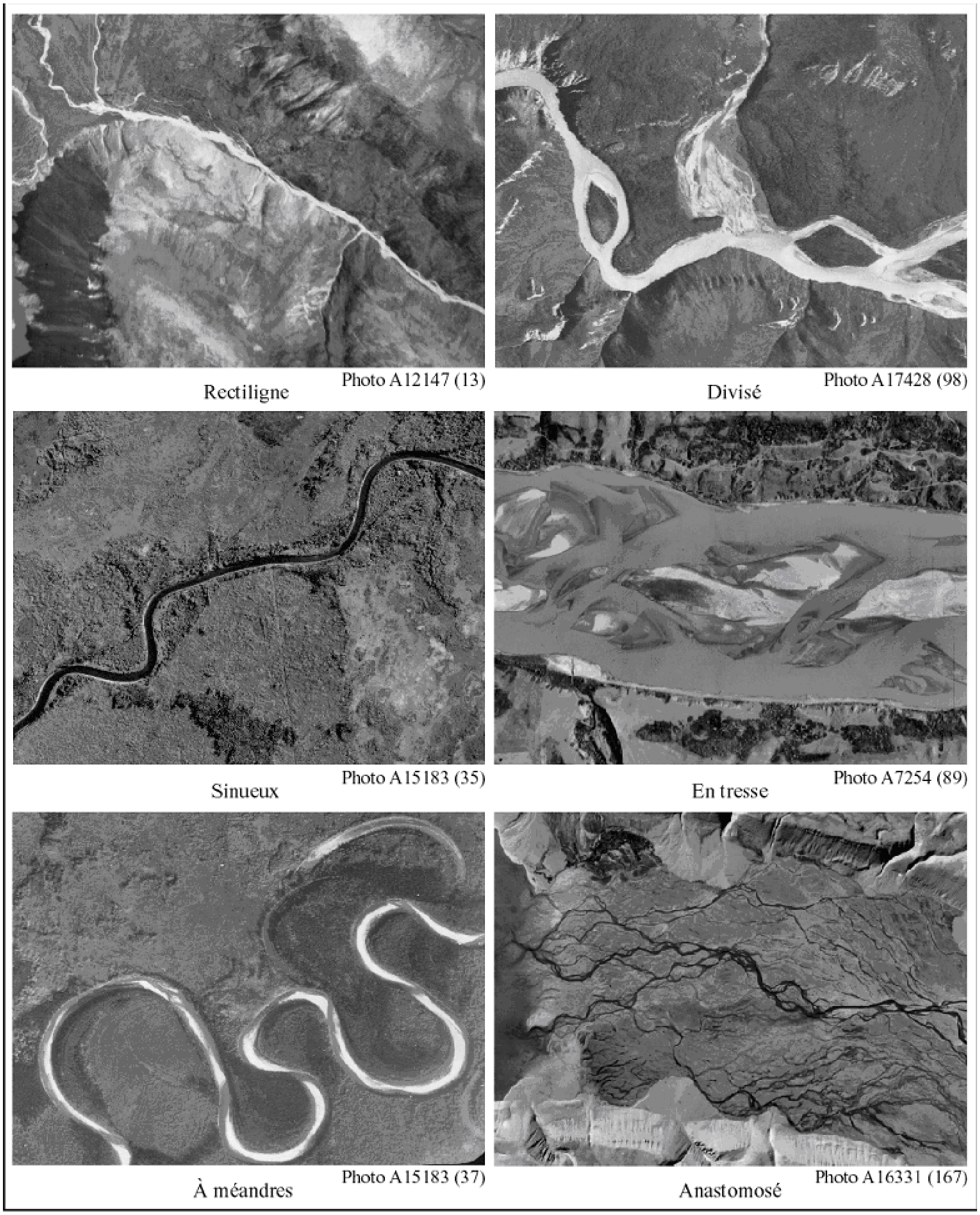


Figure 12 : Illustration of main watercourse shapes.

8- Interpretation

8.1- Critical path

The critical path encompasses two phases: distinguishing and delimiting the form, and then identifying it.

8.1.1- Distinction and delimitation

The determinant criterion for differentiating zones of permanent water from all other entities is the presence of water. However, care must be taken not to confuse some parts of permanent watercourses or waterbodies with wetlands (cf. the *marshes, swamps, and bogs*, *tundra ponds*, and *palsa bog* fact sheets) and intermittent watercourses and waterbodies (cf. the *intermittent water* fact sheet).

In the case of watercourses, the second criterion is the linearity of the entity. However, the type of hydrological network must be considered so as to maintain this linearity even when the watercourse seems to be discontinuous because it is obscured by trees (Figures 10 to 12). The main problems one encounters plotting a watercourse thus occur in its upstream, more wooded stretches: Where does it end? If it cannot be seen on satellite images, we suggest obtaining supplementary observations from recent aerial photography or satellite imagery with a greater spatial resolution.

The second criterion for a waterbody is its rounded shape, which has no equivalent among other natural entities. The only limitation is in terms of the detail of the imagery. The boundary of cartographical representation, which is a diameter of 1 mm at the scale of 1:50,000, corresponds to a surface of approximately 9 pixels (3 x 3).

To be able to correctly identify permanent water, we must ensure that the image was taken during low tide in coastal (marine, estuarine, or lagoonal) environments and outside of periods of flooding or drought in fluvial and lacustrine environments.

Delimitations drawn from satellite imagery create issues of precision. This is exacerbated to the extent that the spatial resolution of images is poor (higher-dimensional pixels). The transition between water (black pixels in band 4) and land (whitish pixels) is thus captured by pixels of an intermittent hue (grey).

8.1.2- Identification

The identification process requires that the analyst address the various elements of confusion and recognition (Tables 4 and 5). The greater the analyst’s knowledge and experience, the more accurate the outcome of this labour of discrimination will be.

8.2- Cross-checking with complementary sources of information

Some of the difficulties delimiting permanent water can be avoided by consulting ancillary sources of documentation.

In coastal (marine, estuarine, or lagoonal) environments, the precise delineation of the shoreline on the image can be verified by obtaining the level of the tide at the time it was taken (date, time). This can be done it two ways. (1) Consult the Canadian Tides and Current Tables for the corresponding region and year. These tables are produced annually by the Canadian Hydrographic Service (Department of Fisheries and Oceans). (2) Submit an ad hoc request (free) to the Canadian Hydrographic Service indicating the section of shoreline covered by the image, the date and time it was taken, and whether the desired information is for chart data (fast response) or geodetic data (slower response): Bernard Labrecque, Institut Maurice-Lamontagne, Mont-Joli (telephone: 418 775-0600 ; e-mail: labrecqueb@dfo-mpo.gc.ca).

Accurate delimitations of the low-flow channel of a watercourse or the mean low-water level of a lake can be verified by obtaining rainfall readings from meteorological stations in or near the catchment basin corresponding to the sector under study for the days and weeks before the image was taken, and of water levels and flows from hydrometric stations on watercourses and lakes that are so equipped on the day the image was taken. The information is available online from the Environment Canada's Water Survey of Canada at the address: http://www.wsc.ec.gc.ca/products/main_e.cfm?cname=products_e.cfm.

Information on hydrometric data is in the HYDAT database. This database consolidates archival statistics from 2481 in-service and 5300 mothballed gauging stations, both provincial and territorial, as well as from electrical utilities (though only from before 1994 in their case). For recent or real-time data, it is necessary to contact the regional offices of Environment Canada. The addresses are on the site. For example, for Quebec: Guy Morin (telephone: 514 283-2048 ; e-mail: guy.morin@ec.gc.ca).

Information on real-time and archival records of daily precipitation for nearly all meteorological stations in Canada can also be found there.

In some instances, determining whether shoals are present may require using bathymetric charts. Nautical charts of varying scales have been created for navigable watercourses and waterbodies, including the Great Lakes and international lakes, by the Canadian Hydrographic Service. These charts can be consulted in the offices of the department and in the map collections of universities, among other places. They can also be purchased from Government publications (http://www.fedpubs.com/charts.htm). For the remaining lakes, check with each province or territory for the responsible agency. For example, in Quebec, charts were created for hundreds of lakes by the Quebec Streams Commission (1910 to 1940), the Ministère des richesses naturelles du Québec (1960 and 1970), the Ministère du tourisme, de la chasse et de la pêche du Québec (1930 to 1970), the Ministère de l'environnement du Québec (1970 and 1980), and a handful of other public and private bodies.

9- Elements of confusion

Large watercourses and waterbodies cannot be confused with any other entity. Nonetheless, some segments of these waterbodies and watercourses, as well as smaller ones, can be confused with other entities or misinterpreted (Table 4).

Narrow watercourses (less than 25 m wide) can only be confused with scarce linear entities (**Table 5**). However, some intermittent stretches can be confused with permanent watercourses, especially near the headwaters, if the image is taken during periods of high waters, whence the importance of imaging when the water level is near its mean.

The information in Tables 4 and 5 is premised on the analyst using band 4 (IR) of the image to identify the presence of water.

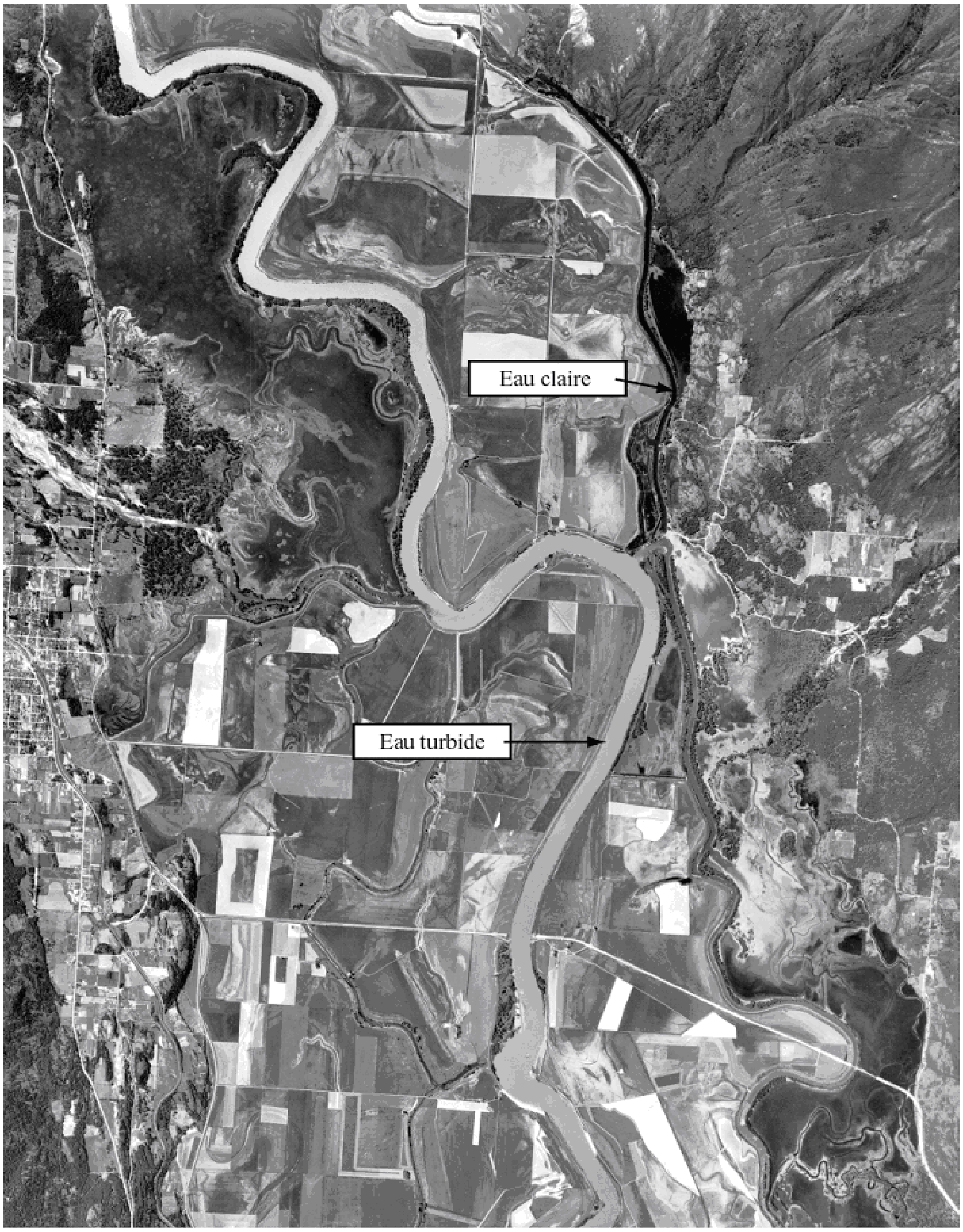
Table 4: Elements of confusion and recognition between permanent waterbodies (including large watercourses) and other entities or forms

Entity or form	**Elements of confusion**	**Elements of recognition**	**Examples**
Intermittent water	- High water level	- None, except using imagery corresponding to the desired water level	**Figure 17**, cf. fact sheet *interm. water* (Fig. 16)
High turbidity	- Concentration of suspended sediments affecting the spectral response and the hue	- Absence of texture - Flatness of surface - Localization on the edge of the water surface	**Figure 13**,**Figure 14**, **Figure 15**
Aquatic vegetation (floating or emergent)	- Water partially concealed If totally masked: confusion with permanent vegetation	- Flatness of surface - Geometry of floating vegetation or protrusion of emergent vegetation	Figure 10, **Figure 16**
Vegetation	- Water concealed by canopy	- Continuity of the shape's outline	Figure 10
Freshwater marsh	- Presence of water during periods of high water - Flatness of surface	- None, except using imagery corresponding to the desired water level	**Figure 17**
Beaver pond	- Temporary water surface	- Triangular shape - Downstream edge a straight line (dam) - Presence of dead trees	Figure 18
Littoral or fluvial ice	- Water concealed	- Structured ice surface - Edge of water ice-free near the shore - Flatness of surface	**Figure 19**, Figure 20
Frazil ice	- Water partially concealed	- Geometric structure of surface - Irregularity of the phenomenon - Flatness of surface	**Figure 21**
Agitation of the water (ripples or waves)	- Multidirectional reflection from surface	- Flatness of surface - Irregularity of the phenomenon	**Figure 22**
Specular reflection	- Full-spectrum reflection - Sometimes concealed water	- Flatness of surface - Highly localized phenomenon on part of the water surface	Figure 23, Figure 24
Cloud reflection	- Moiré of water surface - Shade	- Flatness of surface - Highly localized phenomenon on part of water surface	**Figure 25**
Water level	- Level too high: encroachment on intermittent water - Level too low: underestimation of permanent water	- None, except using imagery corresponding to the desired water level	**Figure 17**
Shade	- Modification of the hue of part of the surface	- Topographic position - Geomorphic context	**Figure 30**

Cloud shadow	- Modification of the hue of part of the surface	- Topographic position - Geomorphic context - Cloud sometimes visible - Edge of lake less blurred than that of cloud	Figure 31, Figure 32

Table 5: Elements of confusion and recognition between permanent watercourses (<25 m) and other entities or forms

Entity or form	Elements of confusion	Elements of recognition	Examples
High turbidity	- Concentration of suspended sediments affecting the spectral response and the hue	- Linearity of shape - Sinuousness of shape - Continuity of shape - Consistency of hydrographic network - Topographic position	Figure 13
Freshwater marsh	- Presence of water during periods of high water - Flatness of surface	- None, except using imagery corresponding to the desired water level	Figure 26
Vegetation	- Water concealed by canopy	- Segments visible on band 4 and continuity of the shape - Topographic position - Consistency of the hydrographic network	Figure 27
Specular reflection	- Full-spectrum reflection - Sometimes concealed water	- Very localized phenomenon - Continuity of shape	Figure 28
River ice	- Significant reflection - Water concealed	- Topographic position - Continuity of shape - Consistency of hydrographic network	
Water level	- Level too high: encroachment on intermittent water and overestimation of the length of the watercourse - Level too low: underestimation of permanent water and the length of the watercourse	- None, except using imagery corresponding to the desired water level	
Loss (karst)	- Abrupt disappearance of the watercourse	- Identification of the type of hydrographic network - Localization of re-emergence site, if possible - Sometimes topographic position	Figure 29



Source : photo A16660 (87), échelle originale 1 : 64 000, carte 82F/02, 49° 05' N - 116° 37' O, rivière Kootenay (Colombie-Britannique) du 11-07-1959

Figure 13 : Example of a watercourse entirely affected by turbidity with a clear water tributary

Source : photo HMQ98-136 (231), échelle originale 1 : 15 000, carte 21E/12, 45° 31' N - 71° 48' O, lac de Stoke (Québec) du 06-08-1998

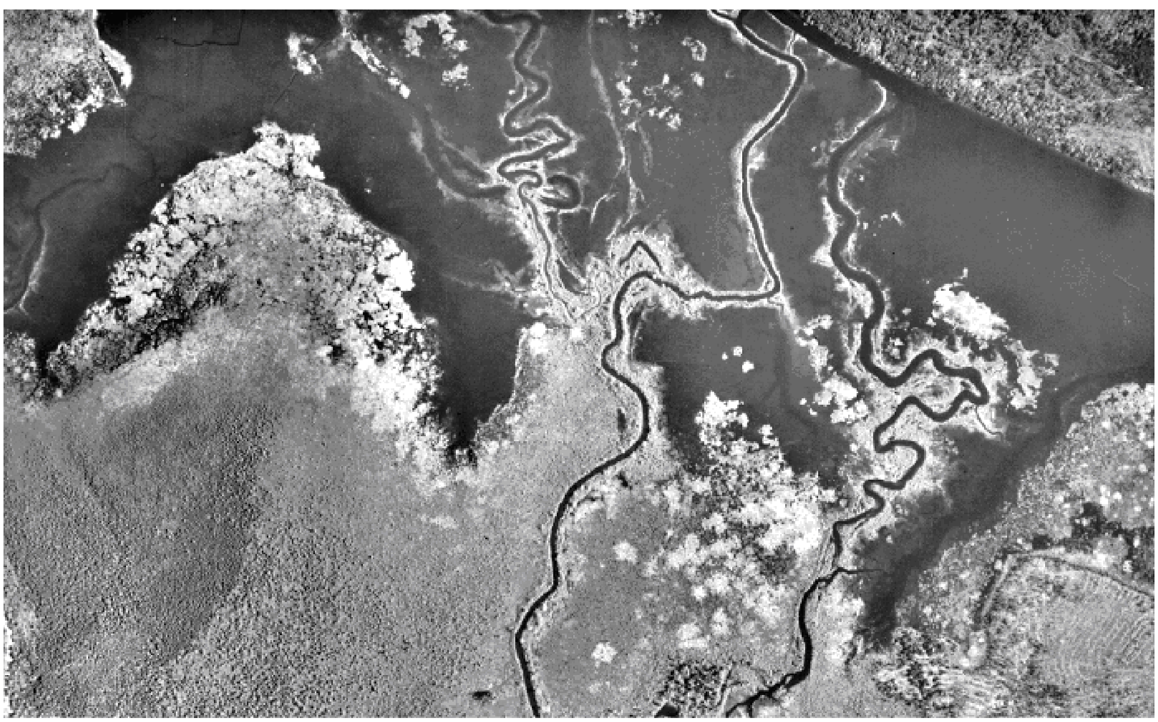
Figure 14 : Example of a waterbody entirely affected by turbidity

Source : photo A11547 (53), échelle originale 1 : 34 000, carte 86O/14,
67° 48' N - 115° 03' O, rivière Coppermine (T.N.-O.) du 27-07-1948

Figure 15 : Example of turbidity at the border of a waterbody. Turbid water comes from tributaries.

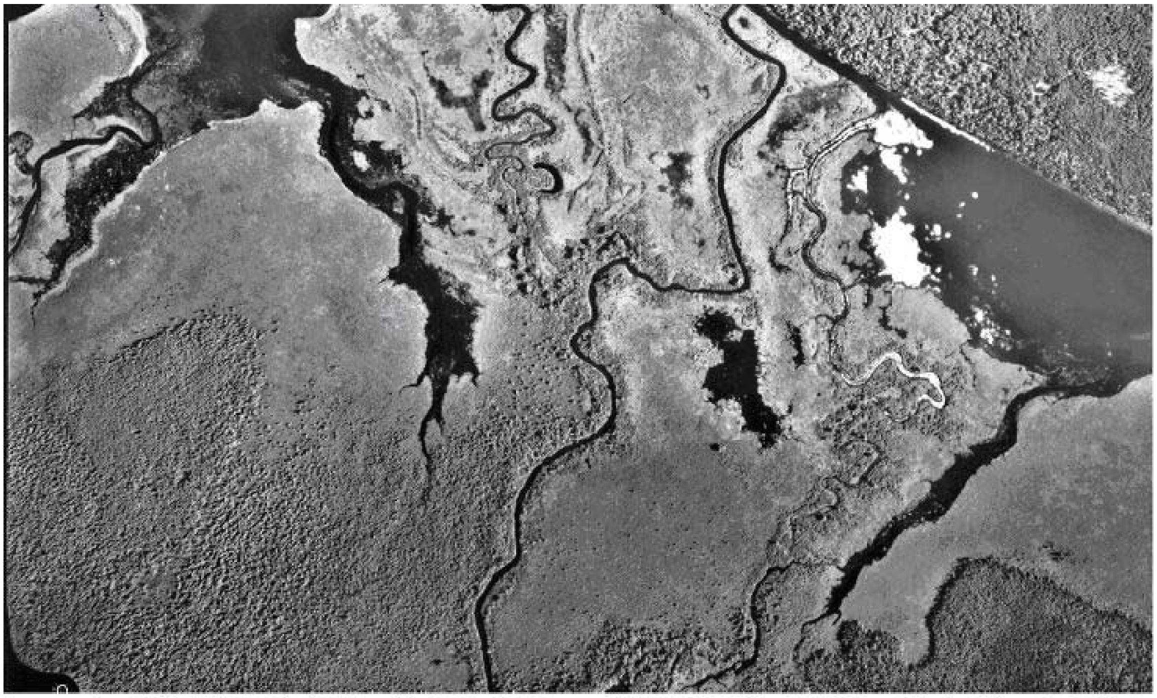
Source : photo HMQ98-133 (10), échelle originale 1 : 15 000, carte 21E/14,
45° 59' N - 71° 05' O, lac Brochu (Québec) du 19-07-1998

Figure 16 : Example of floating aquatic vegetation on a waterbody



Source : photo 6016 (119), échelle originale 1 : 15 840, carte 21E/07, 45° 27' N - 71° 52' O, sud de lac Mégantic (Québec) du 20-05-1960

Figure 17a : Example of water level variation within a waterbody: High level (395.3 m) encroaching the intermittent zone



Source : photo HMQ98-128 (64), échelle originale 1 : 15 000, carte 21E/07, 45° 27' N - 71° 52' O, sud du lac Mégantic (Québec) du 07-07-1998

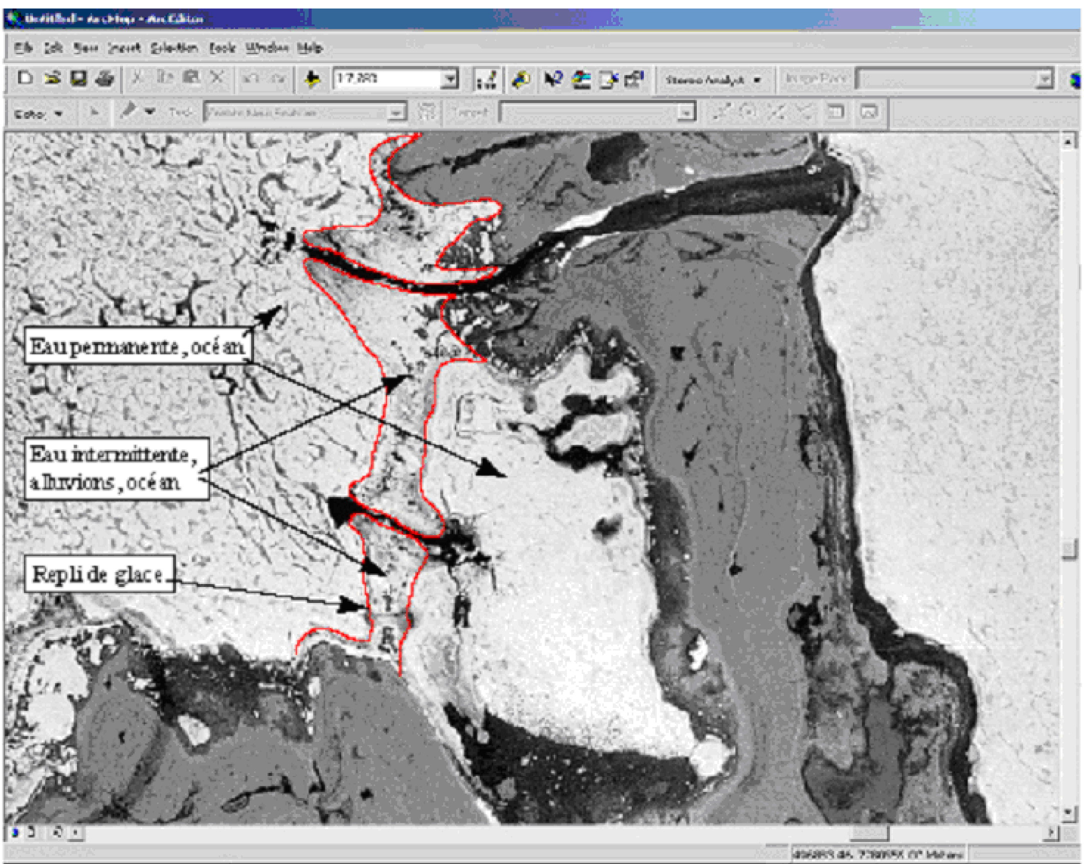
Figure 17b: Example of water level variation within a waterbody: Average level

Source : photo Q85395 (193), échelle originale 1 : 30 000, carte 21E/07, 45°27' N - 71° 52' O, sud de lac Mégantic (Québec) du 01-11-1985

Figure 17c: Example of water level variation within a waterbody: Low level (394.0 m) where the permanent water limit is under estimated

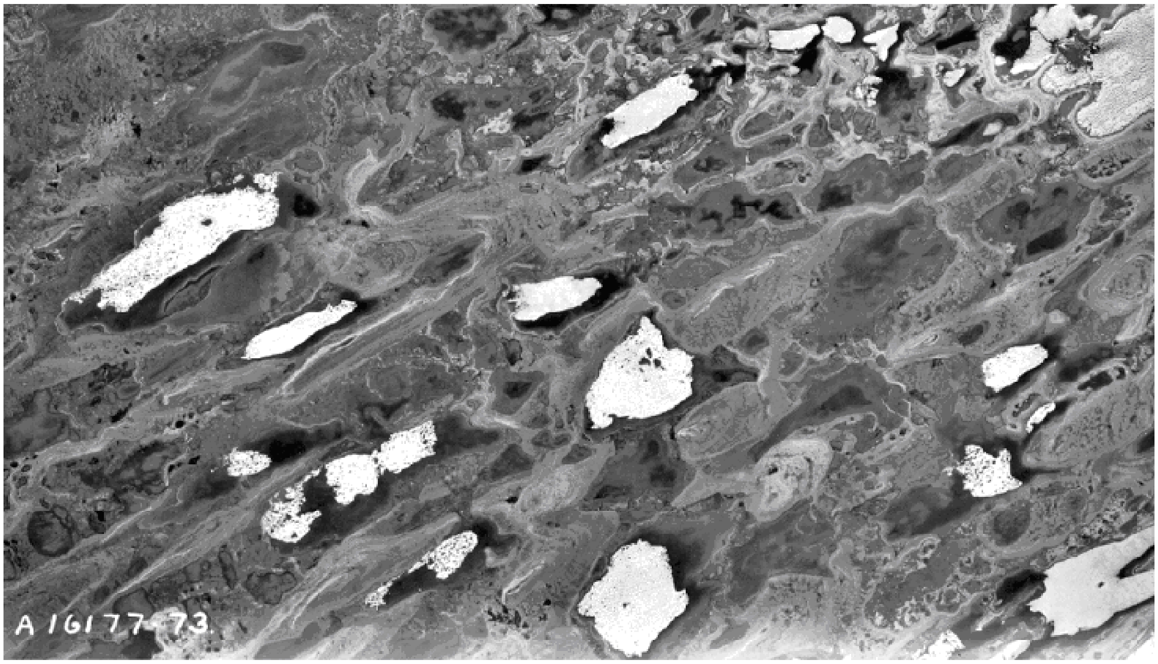
Source : photo HMQ-98-134 (5), échelle originale 1 : 15 000, carte 31H/08, 45° 27' N - 72° 07' O, lac Brompton (Québec) du 19-07-1998

Figure 18 : Example of beaver dams. Note the typical triangular shape



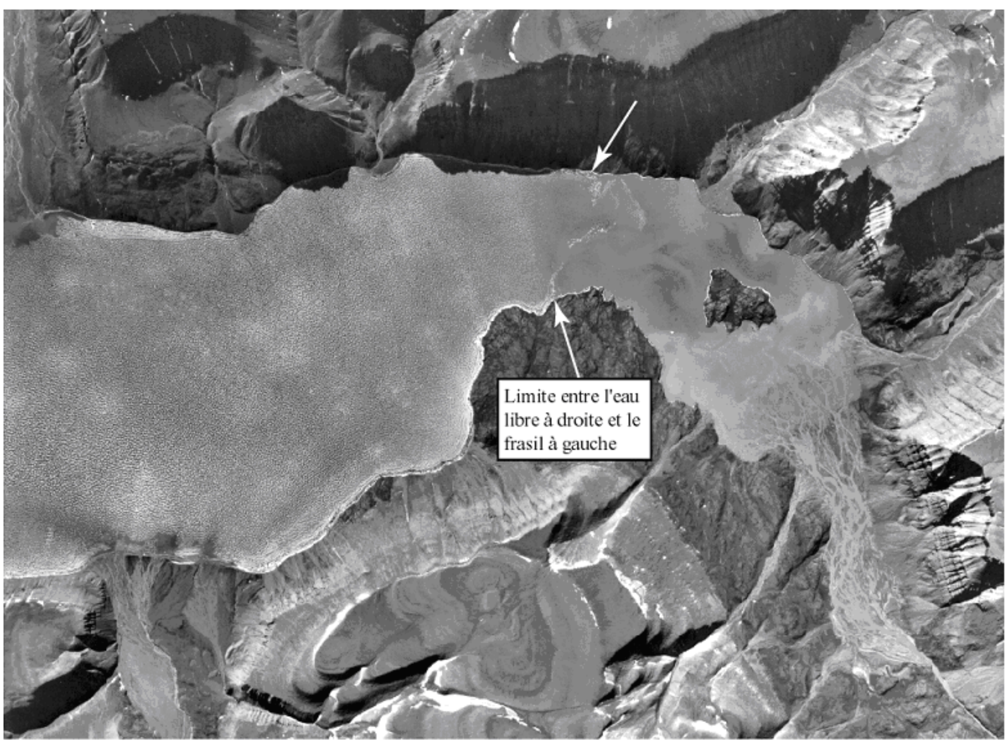
Source : photo A16125 (6), échelle originale 1 : 60000, carte 47F/04, 70° 08' N - 87° 05' O, péninsule Kimakta, golfe de Boothia (T.N.-O) du 04-02-1958 ; montage par le C.I.T. (Sherbrooke)

Figure 19 : Interpretation of permanent and intermittent zones with an ice sheet coverage



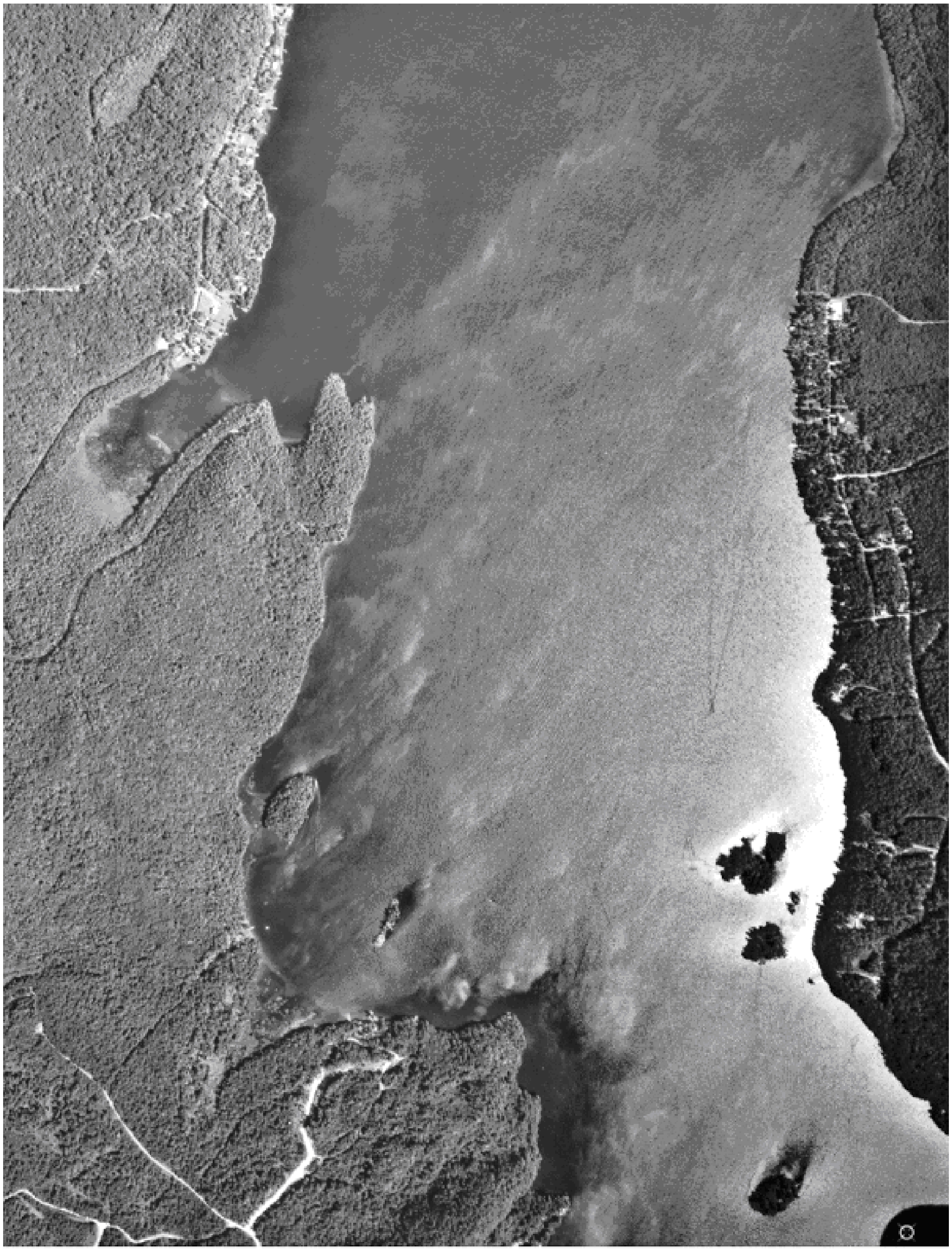
Source : photo A16177 (73), échelle originale 1 : 60 000, carte 67N, 70° 19' N - 101° 29' O, cap Admiral Collision (T.N.-O.) du 25-07-1958

Figure 20 : Example of open water near waterbody shorelines



Source : photo A16762 (79), échelle originale 1 : 60 000, carte 48N, 74° 30' N - 86° 13' O, Burnett Inlet, Île devon (T.N.-O.) du 25-07-1959

Figure 21 : Example of a frasil cover on a waterbody



Source : photo HMQ98-134 (3), échelle originale 1 : 15 000, carte 31H/08, 45° 26' N - 72° 10' O, lac Brompton (Québec) du 19-07-1998

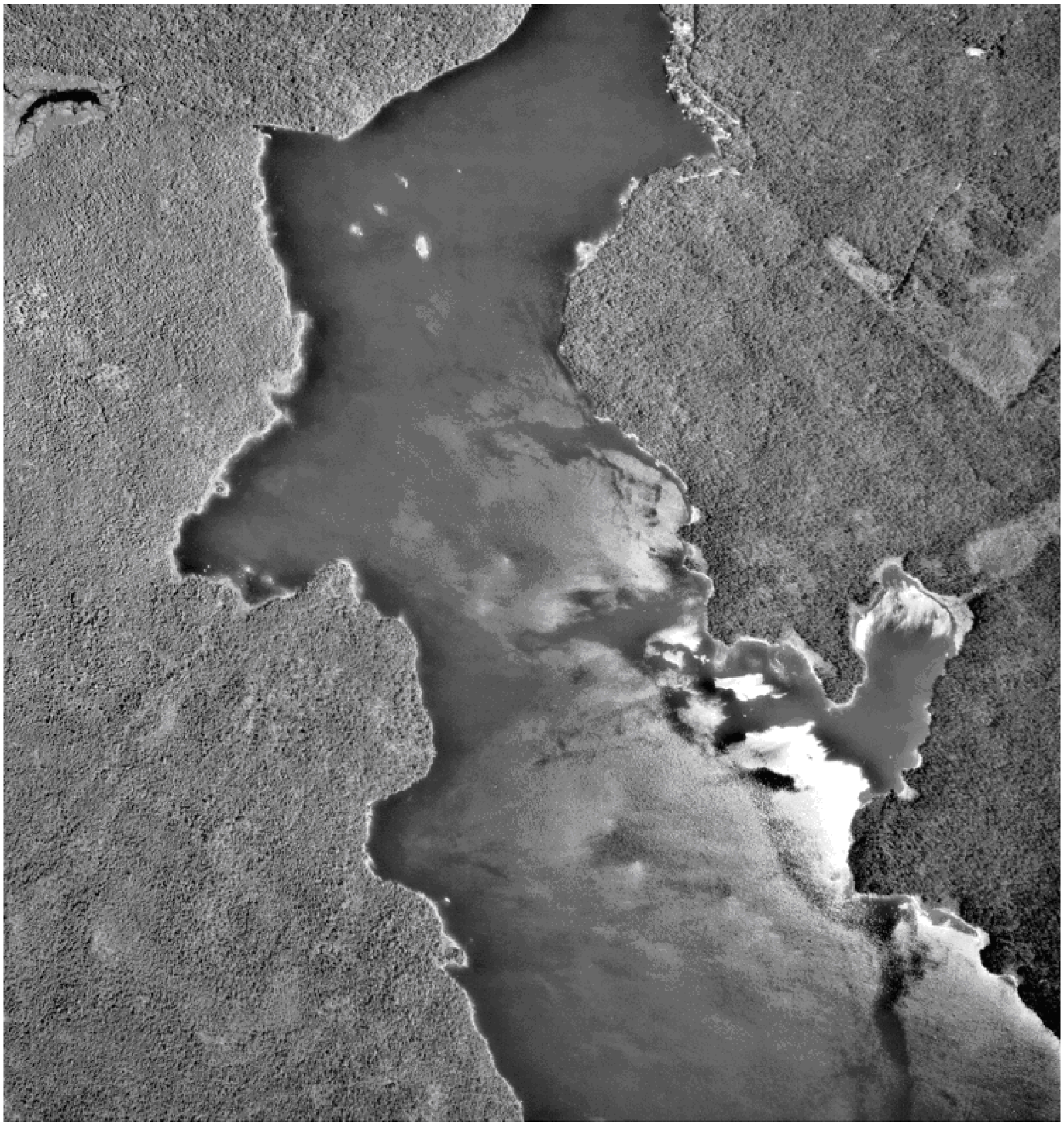
Figure 22 : Example of multidirectional reflexion caused by wind agitating the water surface

Source : photo HMQ98-134 (90), échelle originale 1 : 15 000, carte 21E/12, 45° 36' N - 71° 34' O, Rivière Saint-François près de Bishopton (Québec) du 19-07-1998

Figure 23 : Example of specular reflexion on a portion of a watercourse

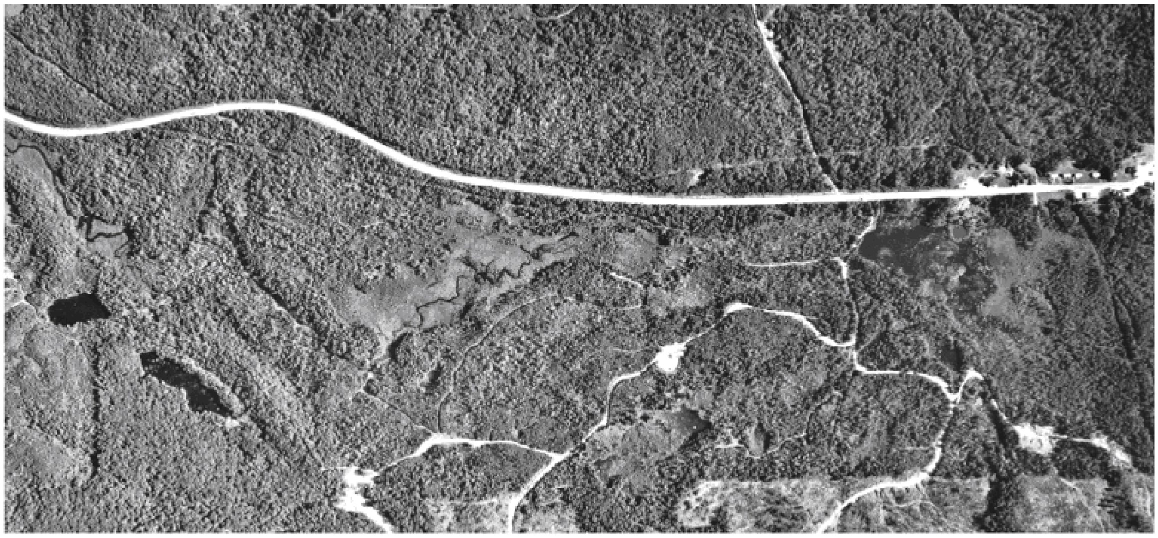
Source : photo HMQ-98-142 (26), échelle originale 1 : 15 000, carte 21E/06, 45° 29' N - 70° 54' O, lac Mégantic (Québec) du 14-08-1998

Figure 24 : Example of specular reflexion on a portion of a waterbody

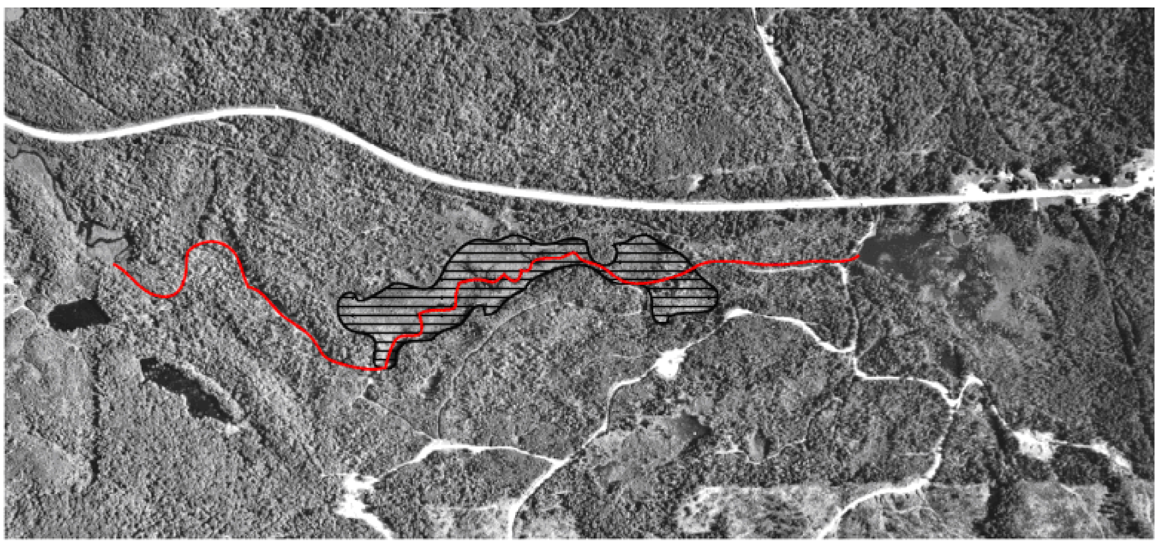


Source : photo HMQ98-127 (39), échelle originale 1 : 15 000, carte 21E/14, 45° 49' N - 71° 10' O, baie Sauvage, lac Saint-François (Québec) du 06-07-1998

Figure 25 : Example of shimmering water surface caused by cloud reflexion



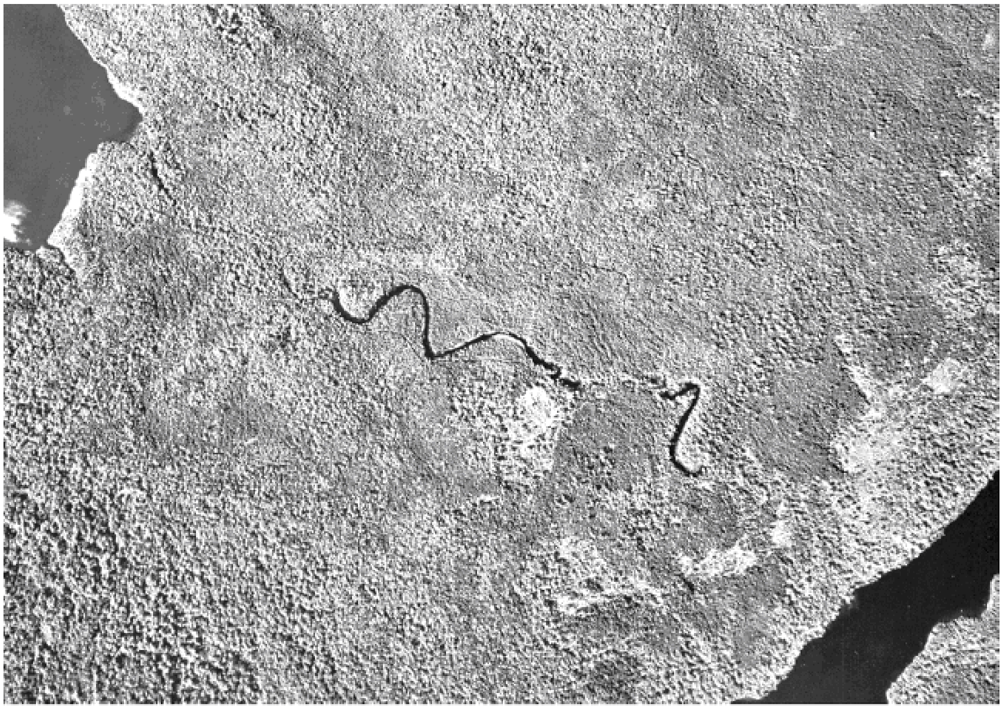
a) Photographie originale



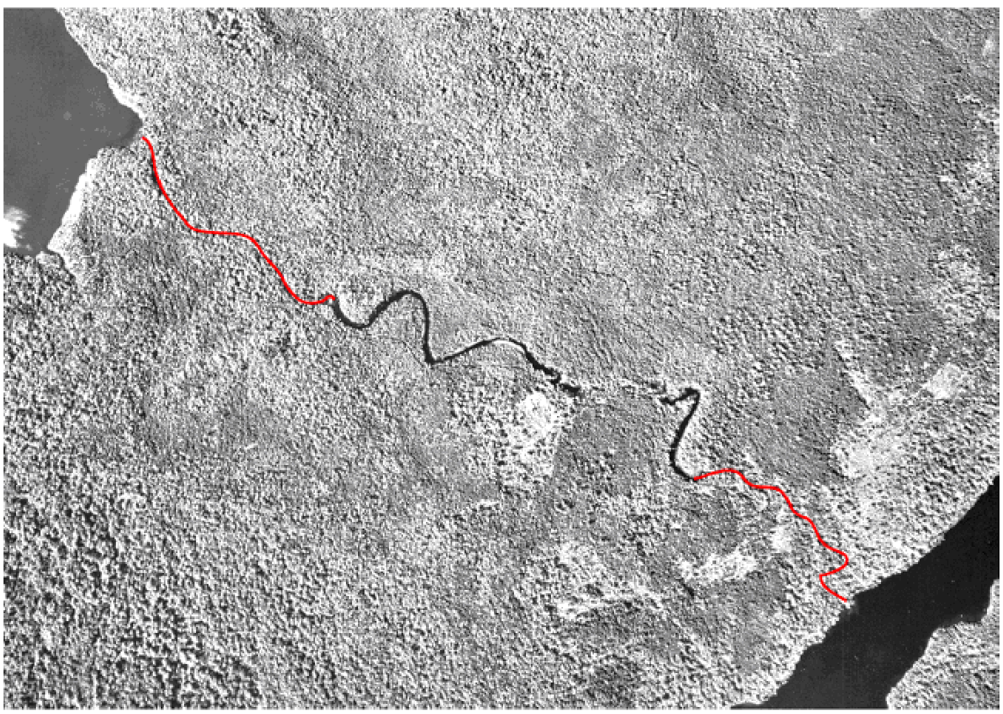
b) Tracé du cours d'eau

Source : photo HMQ98-131 (121), échelle originale 1 : 15 000, carte 21E/07, 45° 22' N - 70° 50' O, région de Woburn (Québec) du 19-07-1998

Figure 26 : Example of a narrow permanent watercourse in a marsh area



a) Photographie originale



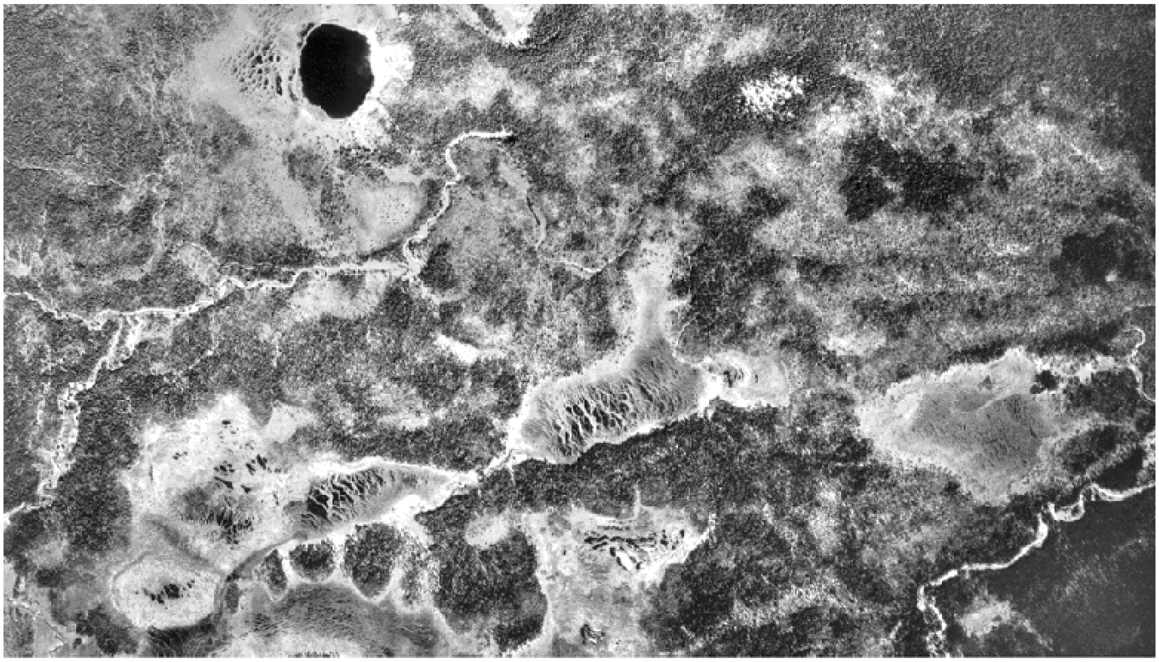
b) Tracé du cours d'eau

Source : photo Québec 1195 (108), échelle originale 1 : 15 840, carte 21E/11, 45° 42' N - 71° 19' O, lac à la Biche (Québec) du 05-1959

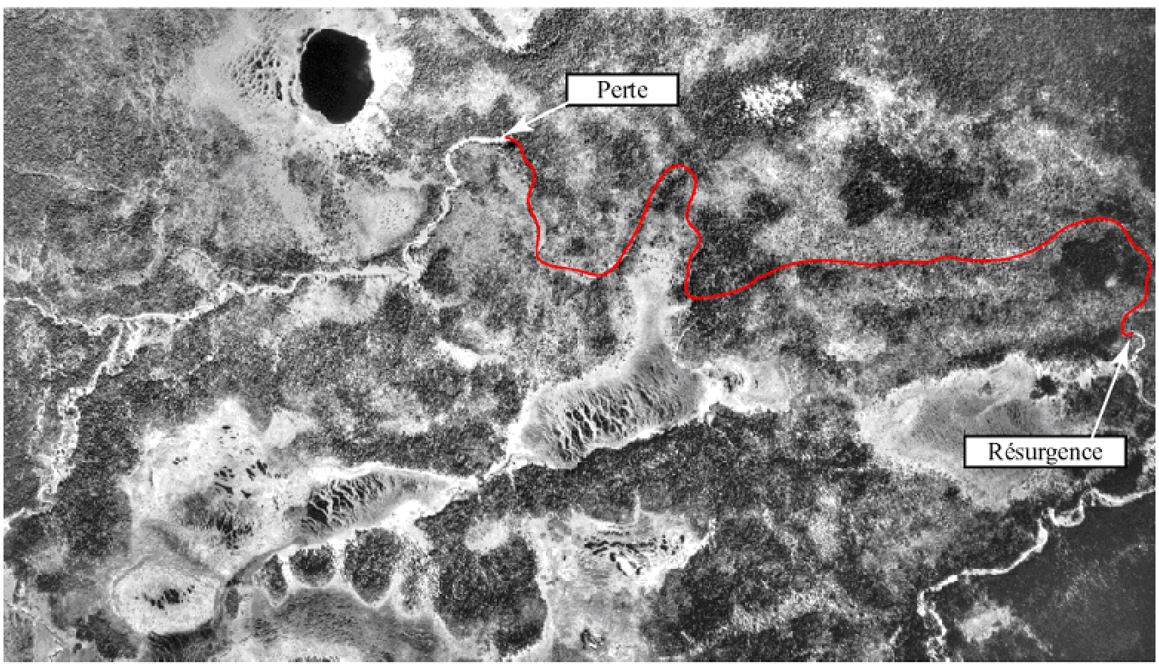
Figure 27 : Example of a narrow permanent watercourse covered by the tree canopy

Source : photo Québec 1196 (124), échelle originale 1 : 15 840, carte 21E/11,
45° 44' N - 71° 09' O, rivière Felton (Québec) du 06-1959

Figure 28 : Example of specular reflexion masking completely a narrow watercourse in different areas



a) Photographie originale



b) Tracé de la paléo-vallée

Source : photo Q73352 (18), échelle originale 1 : 15 000, carte 12E/07, 49° 23' N - 62° 41' O, secteur de la rivière aux Saumons, île d'Anticosti (Québec) du 27-08-1973

Figure 29 : Example of a sink hole and a point of emergence of a narrow watercourse in a karst environment. The visible course of the former valley can be mistaken with an intermittent watercourse

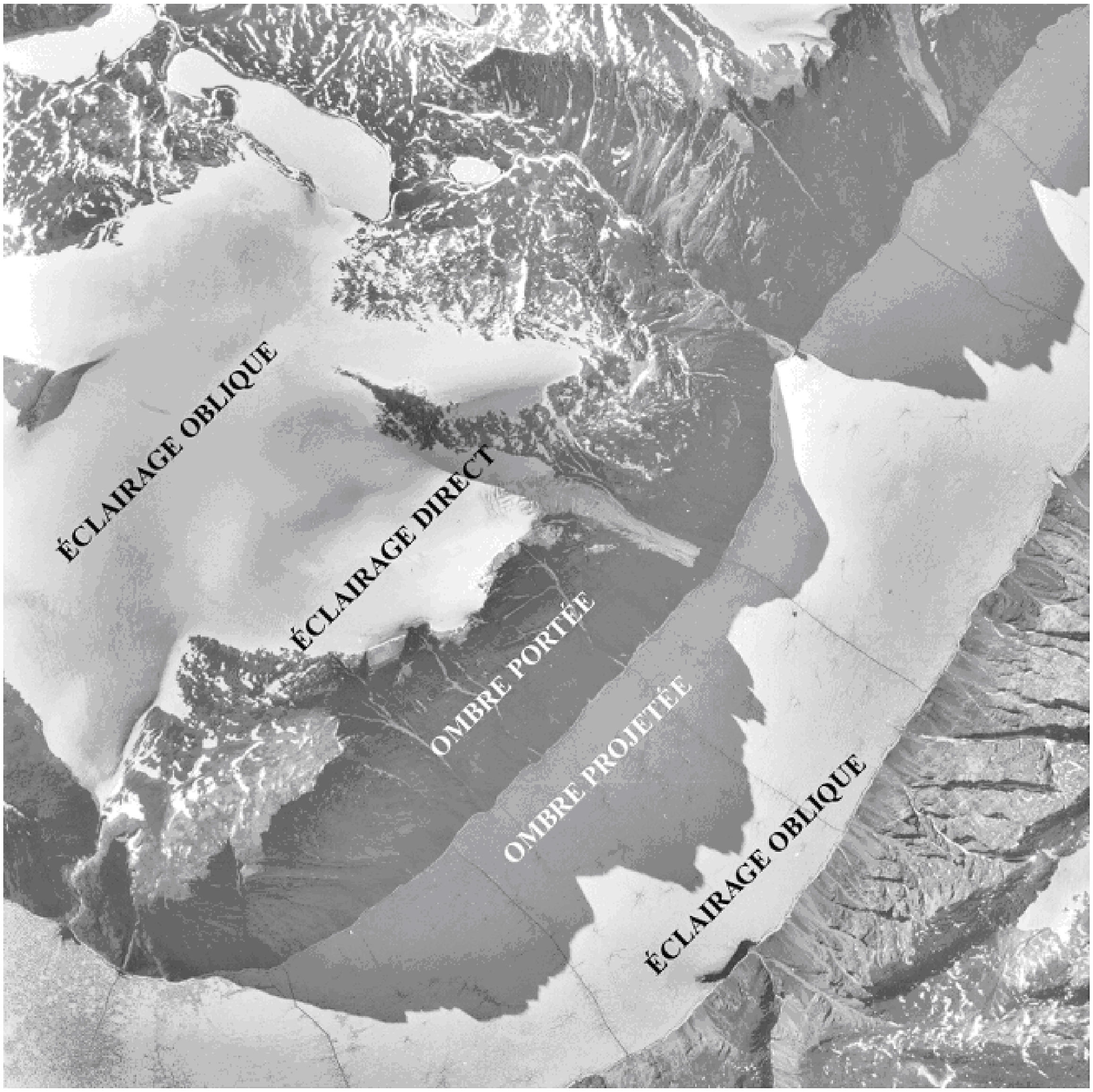
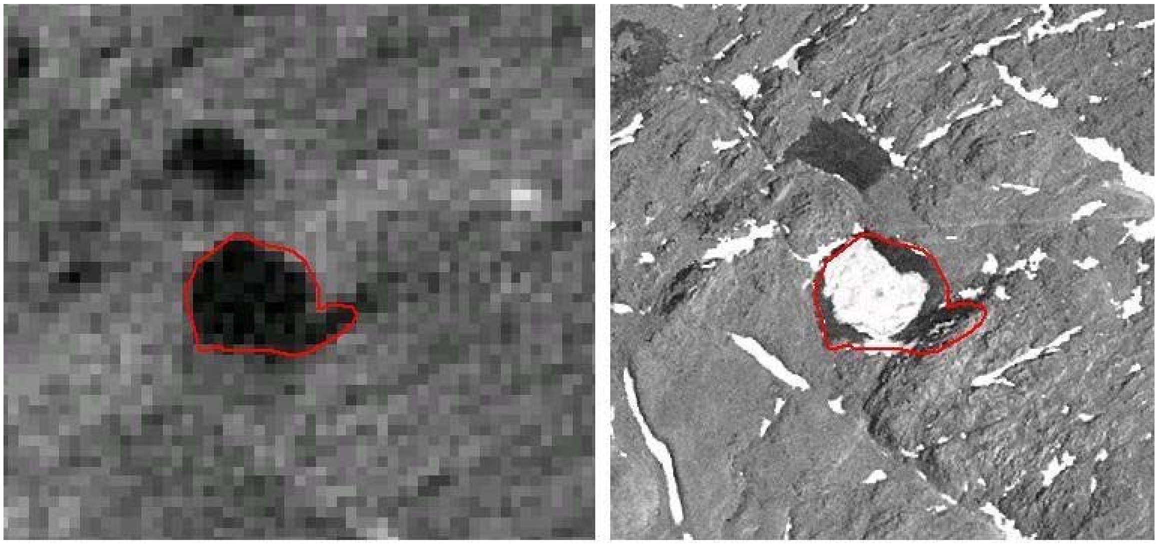


Photo A16101 (24), Ministère de l'énergie, des mines et des ressources du Canada

Source : Provencher et Dubois (en préparation)

Figure 30 : Example of gray tone variation in relation with lighting angle



47F06, 86°40'W 70°26'N, Photo A16082-109 Exemple de mauvaise interprétation
de l'image Landsat à cause de l'omtre du talus

Figure 31: Example of a misinterpretation of the rim of a lake on an ETM+ image (on the left) owing to the shade of a slope that is clearly visible on the aerial photography (on the right).

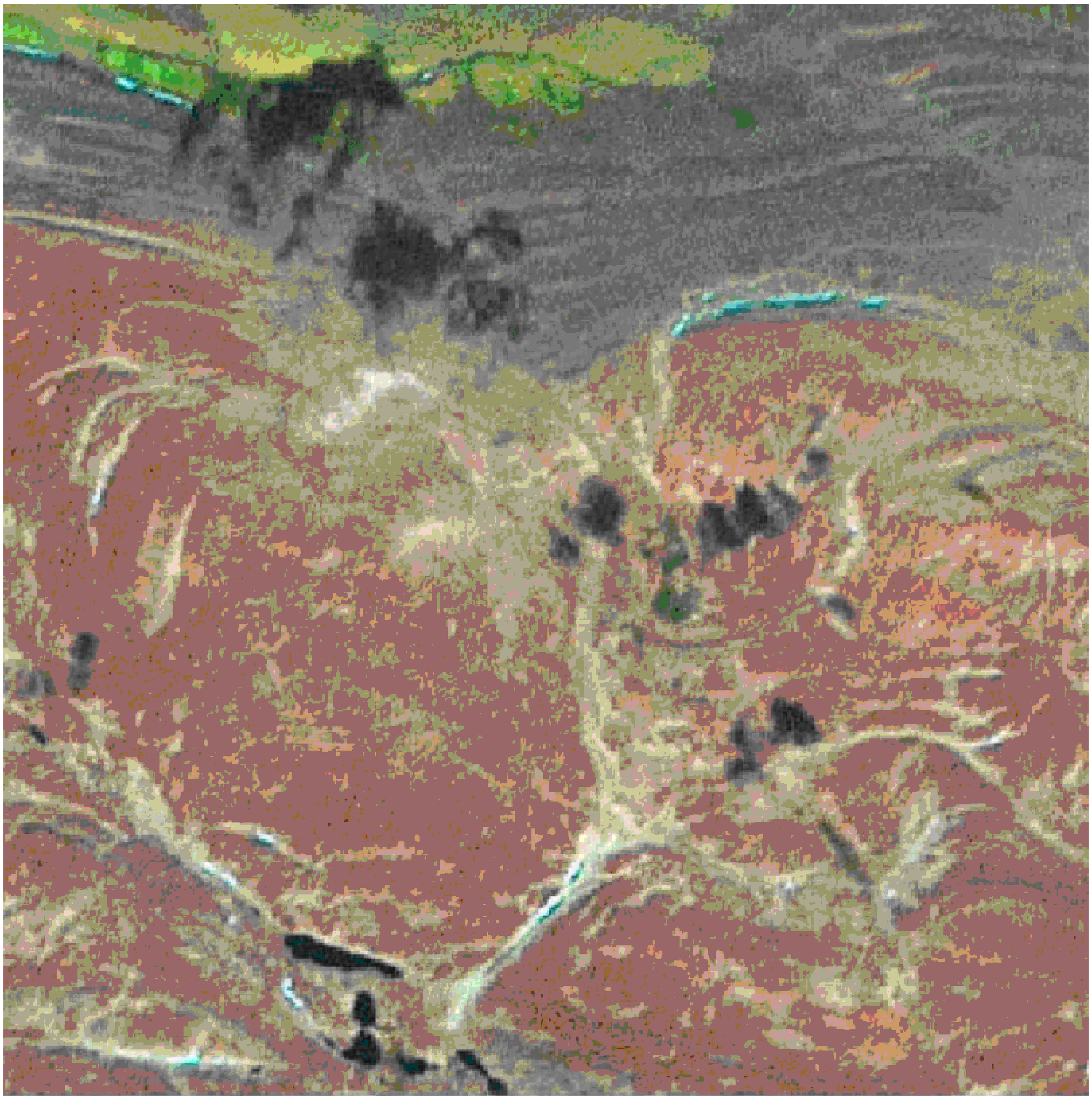


Figure 32: Example of an ETM+ image (combination of bands 5-4-3) on which patches of cloud shadow can be confused with waterbodies.

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Appendix: the meanings of the sections

1. Name of entity

The name of the entity as it appears in the GDB and in Topolan7.

2. Position in hierarchy

The position of the entity in the hierarchical structure of entities in the GDB.

3. Definition

A brief description based on the entity’s principal characteristics and allowing it to be distinguished from any other natural or manmade entity in the GDB.

Only the core features are part of the definition. A detailed description of the characteristics necessary for identification is given in Section 4.

4. Summary table of elements of identification

Presentation of a table summarizing the entity’s characteristics (Section 5), of the optimal conditions for identification on ETM+ imagery and black and white (B/W) aerial photography (Section 6), and of the elements of confusion (Section 9).

5. Characteristics

Categorization and description of the characteristics useful for visual identification of the entity.

5.1. Specific to the entity

Characteristics unique to the entity that allow all aspects useful for its identification to be grasped.

5.1.1. Shape

Distinction between linear, point, and areal shapes, three-dimensional pattern of the entity.

5.1.2. Dimensions

Expanse (length, width, diameter) and height of the entity: minima, maxima, and means.

5.1.3. Topographic position

Location of the entity relative to major landforms: drainage basin, mountain, plateau, plain, valley, slope, etc.

5.1.4. Drainage

Surface moisture, outside of saturated zones, in connection with the texture of the materials in the entity.

5.1.5. Vegetation

Presence of vegetation typical of the entity or patterns of plant associations making it possible to distinguish the entity.

5.2. Relative to the entity's dynamics

Characteristics pertaining to the origin and the state of the entity.

5.2.1. Emplacement process

The agent or set of agents responsible for the entity's emplacement and evolution.

5.2.2. State

Dynamic state of the entity: inherited or current. In the case of inherited features, we speak of paleolandforms; in the case of current landforms, we speak of their ongoing formation.

5.2.3. Spatio-temporal variations

Variations in the entity or its appearance that are functions of cyclical conditions (seasonal, multi-year, etc.) or event driven.

5.3. Relative to the environment

Characteristic of the conditions in the entity's milieu and its relationship with other entities or forms present in this milieu.

6. Optimal conditions for identification

Drawing on documentary sources and the experience of the participants, establishment of the optimal conditions for visual identification of the entity. Using satellite imagery, determine the capability of Landset7 ETM+ to capture the characteristics of the entity and identify the band or combination of bands best for visually distinguishing and identifying the entity. Using B/W aerial photography, identify the hues and textures that are most representative of the entity. In cases in which the relief may be significant, recommend the use of stereoscopy.

7. Examples

Illustrating the entity with examples reflecting several of its aspects:

7.3. Land-based photography

Photographs of the landscape that present one or several examples of the entity's aspects, as they might be seen from the ground.

7.3. Aerial photography

Oblique or vertical aerial photographs that present on or several examples of the entity's aspects, as they might be seen from the air.

7.3. Satellite imagery

Satellite images (from Landsat7 ETM+) that present one or several examples of the entity's aspects, as they might be seen from space.

8. Interpretation

Identification of the entity proceeds from interpreting the information in the imagery or aerial photography and complementary sources of information. The quality of the outcome of this interpretive activity will depend upon the knowledge and the experience of the analyst.

8.1. Critical path

Establishing a unique critical path of interpretation for each entity from the imagery or aerial photography on the basis of its characteristics.

8.1.1. Distinction and delimitation

The possibility of distinguishing and delimiting the shape on the image or aerial photograph has been established and the criteria for success have been described.

8.1.2. Identification

Contrasting the various elements of confusion and recognition with other entities or forms for purposes of identification.

8.2. Use of complementary sources of information

Complementing or cross-checking the interpretation with additional sources of information that are easily accessible, such as those on known Internet sites.

9. Elements of confusion

Identifying the entities and forms with which the entity in question can be confused in a table, along with the differentiating features.

10. Bibliography

A list of useful documents quoted in the previous sections.