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Interpretation guide of natural geographic features from ETM+ Landsat imagery and aerial photography: Waterfalls and rapids

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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

Waterfalls and rapids

2- Hierarchy

Hydrography – watercourses – water disturbance – waterfalls and rapids

3- Definition

Waterfall: an abrupt and substantial (usually over three metres, at CTI), predominantly vertical, discontinuity in the gradient along the lengthwise profile of the watercourse. Cascades are stepwise waterfalls.

Rapids: a tiered discontinuity in the gradient with a drop of several metres along the lengthwise profile of the watercourse, frequently littered with rocks or outcrops and characterized by turbulence.

4- Summary table of elements of identification

Table 2: Summary of elements identifying waterfalls

Shape	View from top: linear and transverse to watercourse View from side: short and sudden vertical drop
Dimensions	Length: metres to decametres Width: metres Height: greater than 3 m (according to CTI)
Topographic position	Abrupt discontinuity in the lengthwise profile of a watercourse
Drainage	Not applicable
Vegetation	None
Emplacement process	Headward fluvial erosion
State	Stable in the human timeframe
Spatio-temporal variations	Stable form, but appearance may vary seasonally with stream discharge
Environment	Usually regional change in slope or tectonic accident
Identification on imagery	Grey hue on band 4 (IR) Change of altitude with DEM
Identification with B/W aerial photography	Change of altitude with stereoscopy More or less whitish hue More or less rough texture
Elements of confusion	Rapids, alluvium, dams, bridges on dams, high-water level

Table 3: Summary of elements identifying rapids

Shape	View from top: uneven surface across entire width of watercourse View from side: stepwise vertical drop of variable length

Dimensions	Length: metres to decametres Width: metres to decametres Height: decimetres to decametres
Topographic position	More or less abrupt discontinuity in the lengthwise profile of a watercourse
Drainage	Not applicable
Vegetation	None
Emplacement process	Headward fluvial erosion
State	Stable in the human timeframe
Spatio-temporal variations	Stable form, but appearance may vary seasonally with stream discharge
Environment	Upper reaches of drainage basins Jagged relief
Identification on imagery	Grey hue on band 4 (IR) Change of altitude with DEM
Identification with B/W aerial photography	Change of altitude with stereoscopy More or less whitish hue More or less rough texture
Elements of confusion	Waterfalls, alluvium, boulders, specular reflection, water disturbance, high-water level, tidal bore, tidal rapids

5- Characteristics

5.1- Specific to the entity

5.1.1- Shape

Waterfall: view from top: a straight line cutting across the watercourse, typically followed by more or less round basin; view from side: short and steep drop.

Rapids: view from top: a straight line cutting across the watercourse, or elongated along the watercourse if a series of rapids occurs close together; view from side: stepwise vertical drop of variable length.

5.1.2- Dimensions

A) Waterfall

Length: metres to decametres.
Width: a few metres to decametres, depending on the width of the watercourse.
Height: a few metres to several decametres (over three metres, at CTI).

B) Transversal rapids

Length: a few metres to a few decametres.
Width: metres to decametres, depending on the width of the watercourse.
Height: decimetres to metres.

C) Series of rapids

Length: several decametres to several hundred metres, sometimes more.
Width: metres to decametres, depending on the width of the watercourse.
Height: metres to decametres.

5.1.3- Topographic position

Waterfalls and rapids are found in riverbeds. They are generally located in places where the contour lines crossing the watercourse are squeezed together, indicating a relatively abrupt vertical drop in the gradient along the lengthwise profile of the watercourse.

5.1.4- Drainage

Not applicable.

5.1.5- Vegetation

Waterfalls and rapids are devoid of vegetation. The banks of some rapids may be masked by the canopy, but their shape always remains recognizable.

5.2- Relative to the entity's dynamics

5.2.1- Emplacement process

Waterfalls appear where there are escarpments created by: (1) a tectonic event (fault or fracture); (2) differential headward fluvial erosion (from downstream toward upstream) of rock that is soft or very fractured by the watercourse and rock that is hard or less fractured; (3) capture of one watercourse by another that flows through a valley that has been over deepened, e.g. by a glacier, resulting in a hanging valley (Bravard and Petit, 2000).

Rapids occur at gentle kinks in the gradient caused by either a tectonic event or differential headward fluvial erosion in combination with the glacial or gravitational deposit of boulders (fallen from steep rocky slopes) onto the riverbed (Bravard and Petit, 2000).

5.2.2- State

Waterfalls and rapids are inherited features that develop over millennia. Some may, however, appear subsequent to the thawing of a watercourse in a glacial milieu, or a breach in a dam.

5.2.3- Spatio-temporal variations

Waterfalls and rapids only change over millennia if humans do not alter them or submerge them by damming the watercourse.

Their appearance may, however, depend on stream discharge at the time the image is taken.

5.3- Relative to the environment

Waterfalls are associated with regional discontinuities in the slope (talus) or tectonic events. Because of headward erosion the waterfall is often located upstream of the fault, especially when the sedimentary rock is particularly brittle.

Rapids are most often found in the upper reaches of drainage basins and in small or medium-sized watercourses on rough terrain.

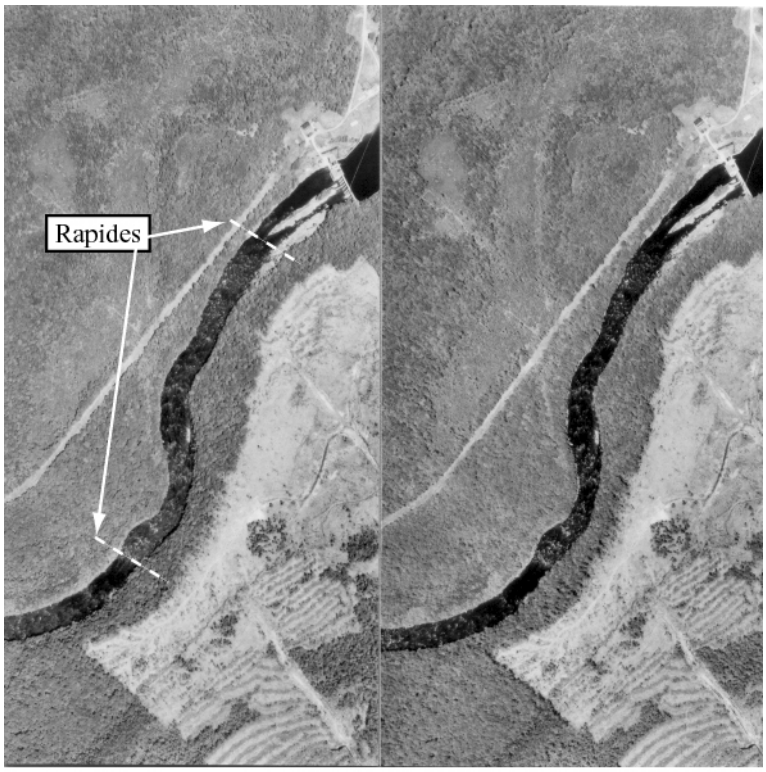
6- Optimal conditions for identification

To properly map all waterfalls and, especially, rapids, images must be taken during times of minimum flow and several days after a precipitation event, since small waterfalls and rapids can be undetectable when the water level is too high.

Waterfalls are much easier to identify from aerial photography than on ETM+ imagery. On aerial photographs stereoscopy facilitates recognition of the change in altitude and the fault in the slope. In addition, the basin and the plume of foam are usually highly visible (whitish hue). Most waterfalls are impossible to identify on ETM+ images and, at the limit, they are mistaken for rapids if the plume of foam is sufficiently large. Using a digital elevation model (DEM) is vital for determining the change in altitude.

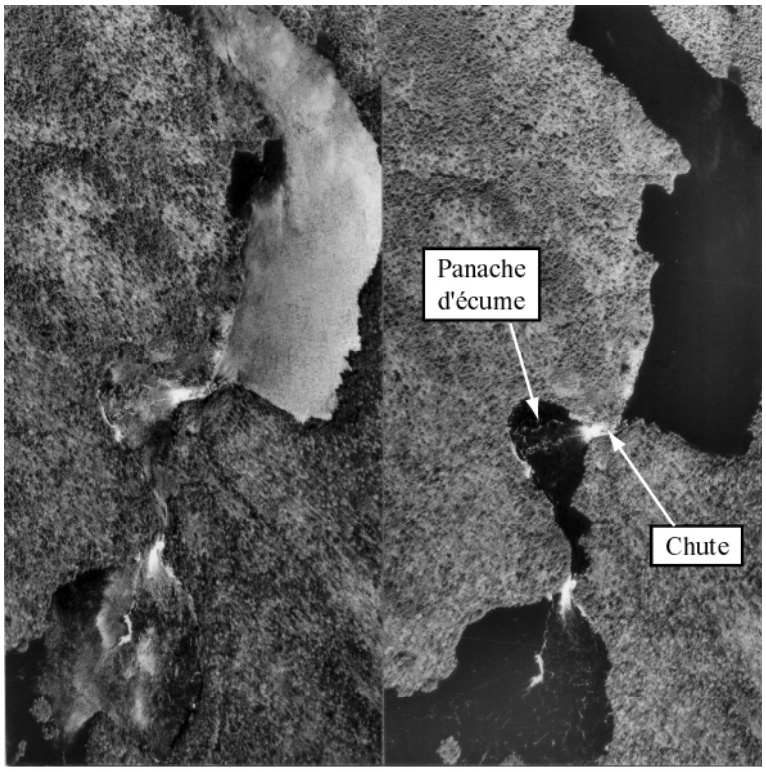
Rapids are also much more readily identifiable on aerial photographs than on ETM+ images. With aerial photography, stereoscopy makes it easier to detect changes in altitude, even when they are less abrupt than in the case of waterfalls. One of the principal identifying criteria is turbulence, which creates a multidirectional reflection and lends a whitish hue and a more or less coarse texture that depends on the gradient. On band 4 (IR) of ETM+ imagery, rapids appear in varying shades of grey. The DEM is useful for evaluating the drop in altitude.

7- Examples



Source : Mercier et al. (1990)

Figure 1 : Stereoscopic example of a rapid with low vertical drop, where less than 50% or the area is covered by blocs or foam

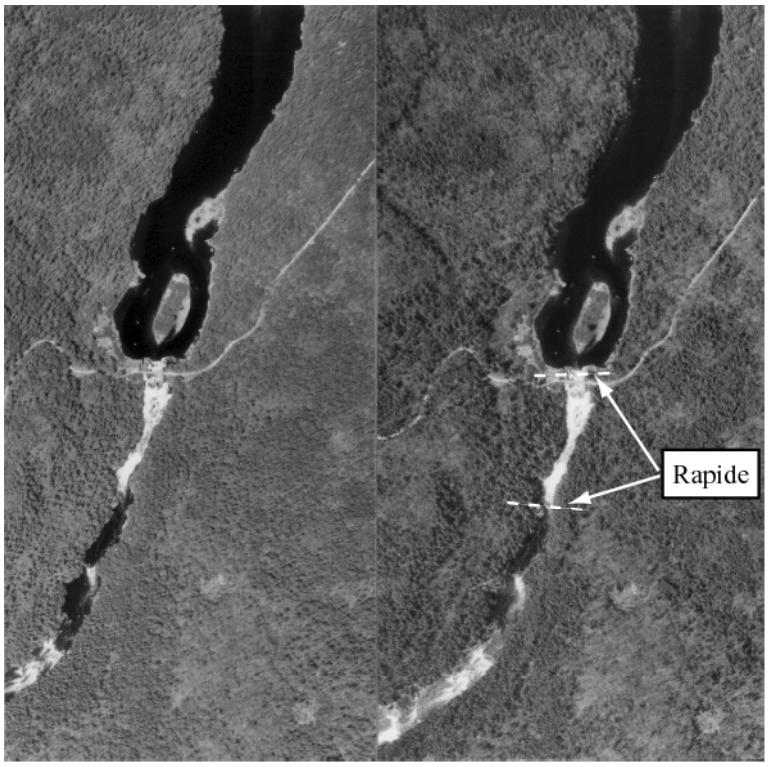


Source : Mercier et al. (1990)

Figure 2 : Stereoscopic example of a waterfall. It is recognized by the foam plume and the pool or basin below.

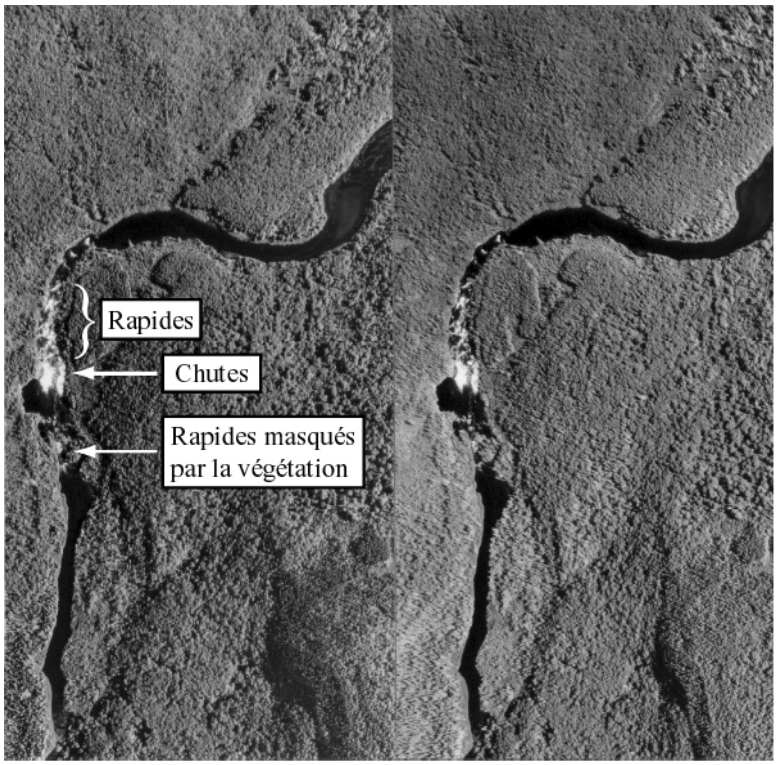
Source : photo Jean-Marie Dubois no 94-18-18 ; aussi " Le Québec en images " no 16848, chute du Granit, rivière Caniapiscau, nord du Québec

Figure 3 : Oblique air view of a waterfall with foam plume and basin below



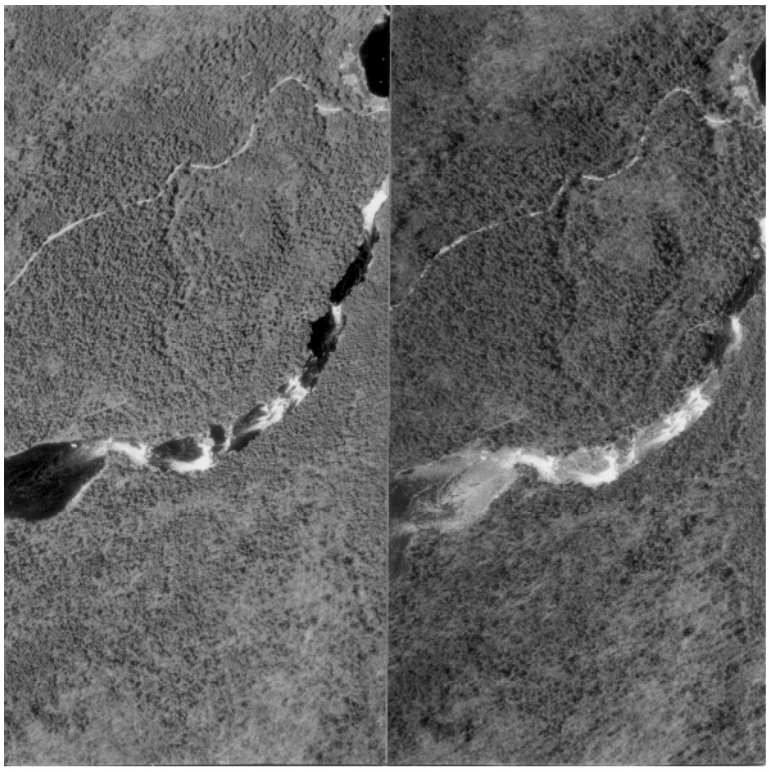
Source : Mercier et al. (1990)

Figure 4 : Stereoscopic example of a rapid with a sudden drop where the surface is covered with foam



Source : Mercier et al. (1990)

Figure 5 : Stereoscopic example of a rapid with average drop where the surface is covered with foam between 50% and 100%. This rapid ends with a waterfall that has a small foam plume and a pool. Below this pool there is a rapid partially masked by tree canopy.



Source : Mercier et al. (1990)

Figure 6 : Stereoscopic example of a serie of rapids at the scale of 1/15 000 that could be captured as a single rapid area at the scale of 1/50 000

8- Interpretation

8.1- Critical path

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

8.1.1- Distinction and delimitation

The key to identifying waterfalls or rapids is the presence of turbulence in a watercourse. However, turbulence can also be caused by dams, so attention must be paid to the regularity of the form.

8.1.2- Identification

The process of identifying waterfalls and rapids requires that the analyst address the various elements of confusion and recognition (Tables 3 and 4). 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

The only supplementary sources of information for locating waterfalls and rapids are existing topographical maps and maps produced by clubs and organizations that practise white-water sports—which have categorized rapids and identified waterfalls on many watercourses with photo-interpretation (Mercier, 1988; Mercier et al., 1990)—and on-site verification. For example, in Québec the Fédération québécoise de canot-kayac has created guides for most of the largest watercourses (http://www.canot-kayak.qc.ca).

Waterfalls can be distinguished from dams by using the national database of dams that are equipped with water level gauges on Environment Canada's Web site: http://www.wsc.ec.gc.ca/products/main_e.cfm?cname=reference_e.cfm.

There are probably also lists of all dams in the provinces and territories. For example, in Québec a complete database of dams over one metre high, including those of the forestry companies, along with their characteristics, is maintained by the Ministère de l'environnement, de la faune et des parcs (http://www.cehq.gouv.qc.ca/index_en.asp).

9- Elements of confusion

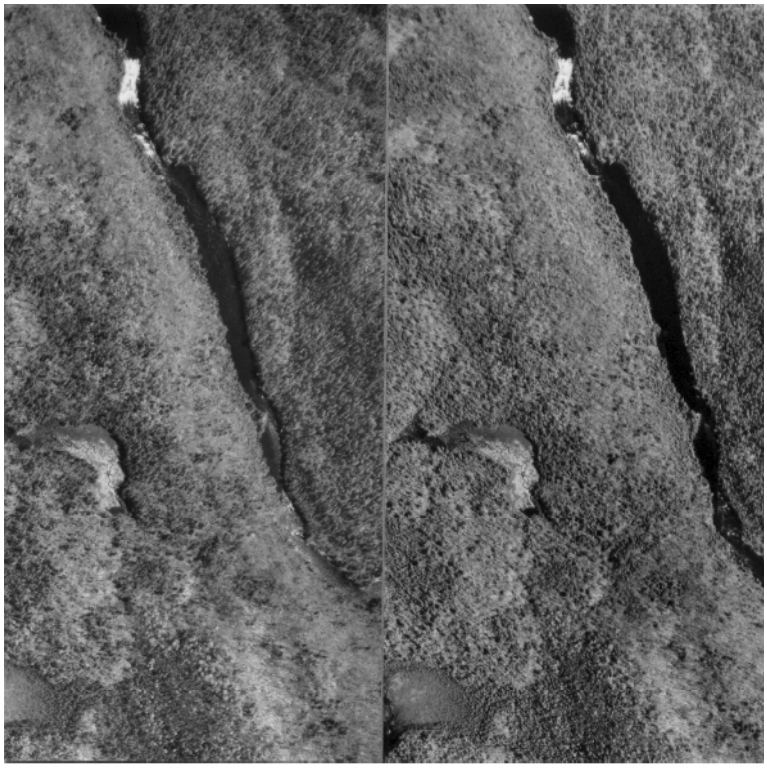
Table 4: Elements of confusion and recognition between waterfalls and other entities or forms

Entity or form	**Elements of confusion**	**Elements of recognition**	**Examples**
Rapids	- Gradient	- By stereoscopy - With the DEM	Figure 7
Alluvium	- Whitish hue of the water	- Topographic position - Geomorphic context - Absence of a low-flow channel	Figure 4
Dam	- If shape is irregular - Absence of visible structure - Whitish hue of the water	- Presence of basin - Absence of infrastructure - Absence of upstream reservoir	Figure 8
Bridge on a dam	- Dam concealed - Whitish hue of downstream water - Turbulence of downstream water	- Virtually none - Absence of upstream reservoir - Supplementary documentation	Figure 9
High water	- Visible lessening of the slope	- None, except using imagery or photography taken at low water	

Table 5: Elements of confusion and recognition between rapids and other entities or forms

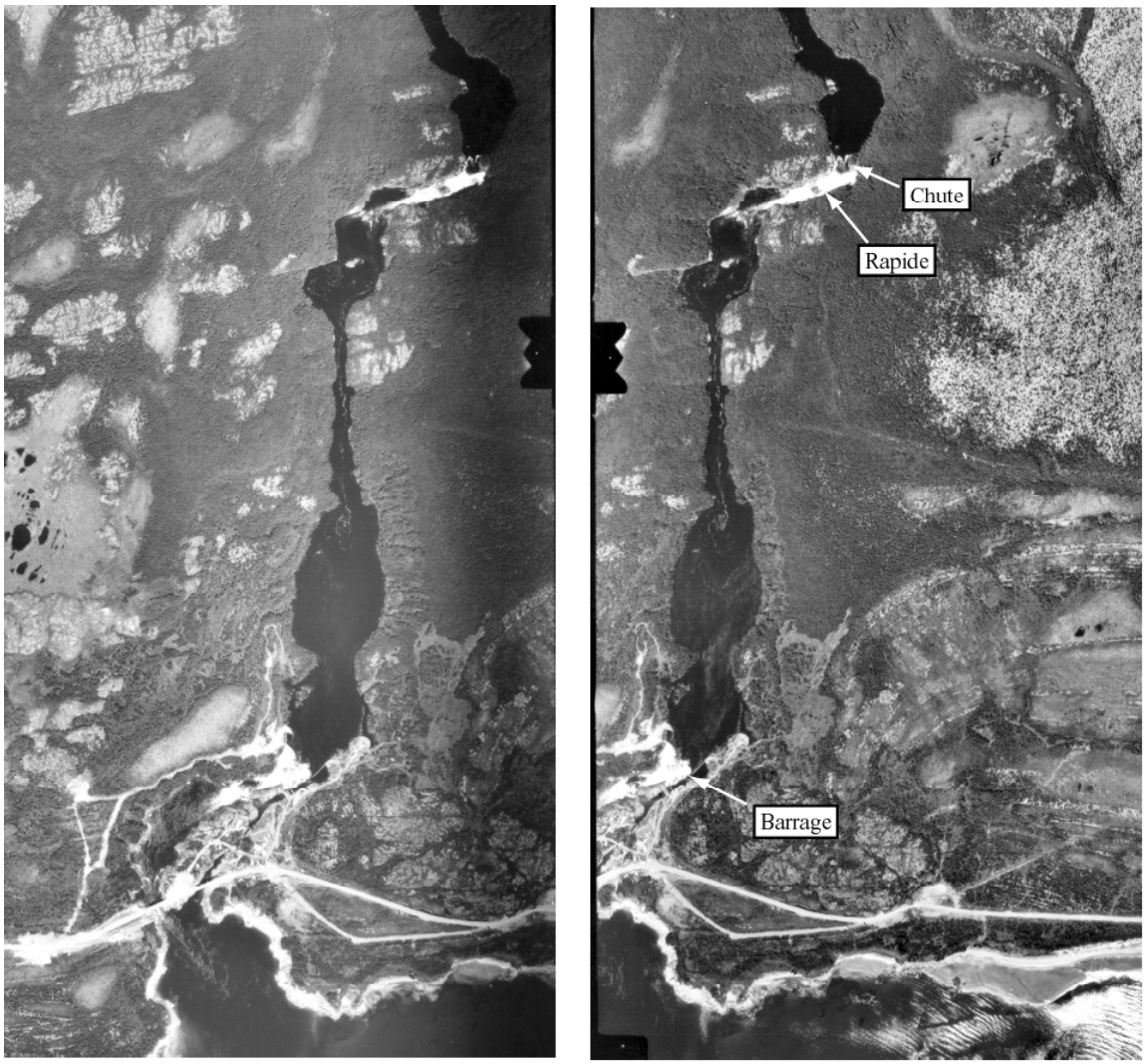
Entity or form	**Elements of confusion**	**Elements of recognition**	Examples
Waterfall	- Gradient	- By stereoscopy - With the DEM	Figure 8
Alluvium	- Whitish hue	- Topographic position - Geomorphic context - Absence of a low-flow channel	Figure 4
Boulders	- Greyish hue - Mottled texture	- By stereoscopy - Band 4 if low boulder density - Bands 4-3-2 if high boulder density	Figure 10
Specular reflection	- Whitish hue - Heterogeneous texture	- Adjacent photography - Band 4	Figure 11

Water disturbance	- Whitish to greyish hue - Heterogeneous texture	- By stereoscopy - Band 4	
High water	- Visible lessening of the slope	- None, except using imagery or photography taken at low water	
Tidal bore	- Whitish hue - Thin irregular form perpendicular to the watercourse	- Zone of turbulence upstream, not downstream - Sector in an estuary - Band 4	
Rapids in tidal zone	- False rapids	- Location in intertidal zone	Figure 12



Source : Mercier et al. (1990)

Figure 7 : Stereoscopic example of a rapid with sudden drop that could be mistaken for a waterfall. The pool is not obvious, neither is the foam plume

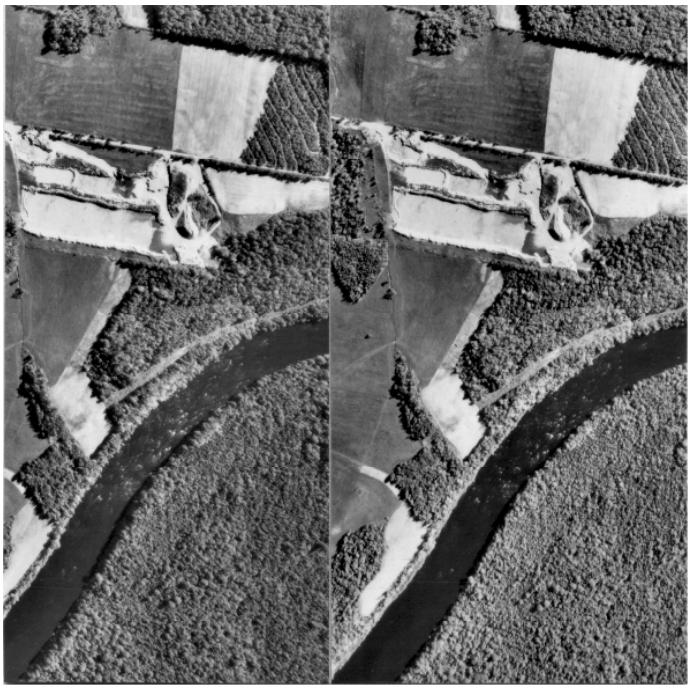


Source : photo Q67806(161-162), échelle originale 1 : 15 840, carte 22I/08, 50° 20' N - 64° 28' O, rivière Magpie, Côte-Nord du Saint-Laurent (Québec) du 28-06-1967

Figure 8 : Stereoscopic example of a waterfall and a hydroelectric dam. The dam can easily be mistaken with a waterfall. The distinctive features for the dam are the derivation channel to the right, the station at the base and the lack of pool or basin below.

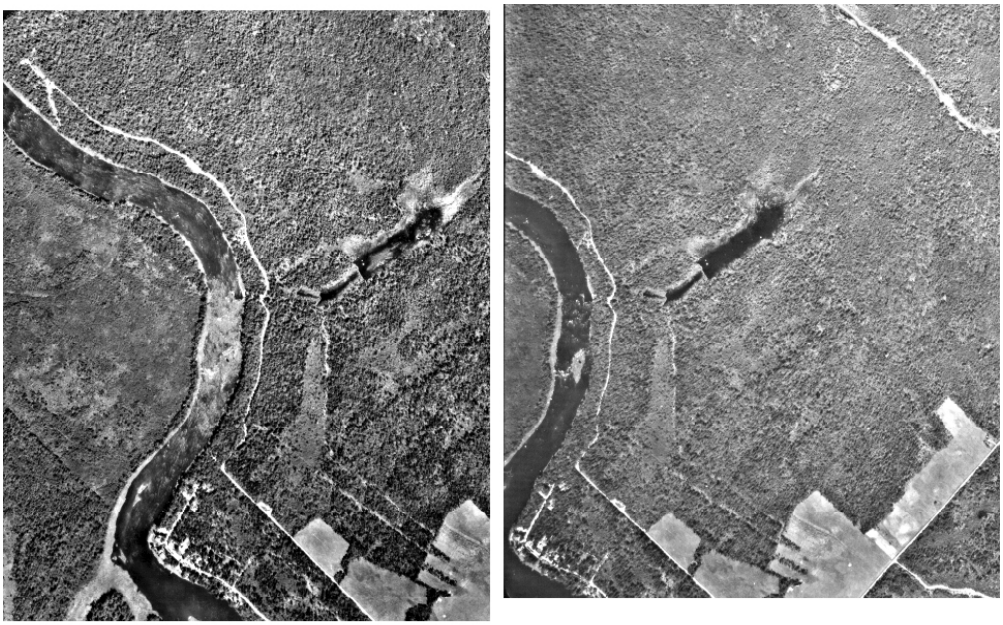
Source : photo HMQ98-121(159-160), échelle originale 1 : 15 000, carte 21E/14, 45° 45' N - 71° 25' O, rivière Saint-François à Saint-Gérard (Québec) du 03-07-1998

Figure 9 : Stereoscopic example of a bridge on a dam. The dam is obvious for an experienced interpreter because water evacuation is done through a local jet. An unexperienced interpreter could omit the presence of this dam and mistake the dam for a waterfall and the water jet for alluvium.



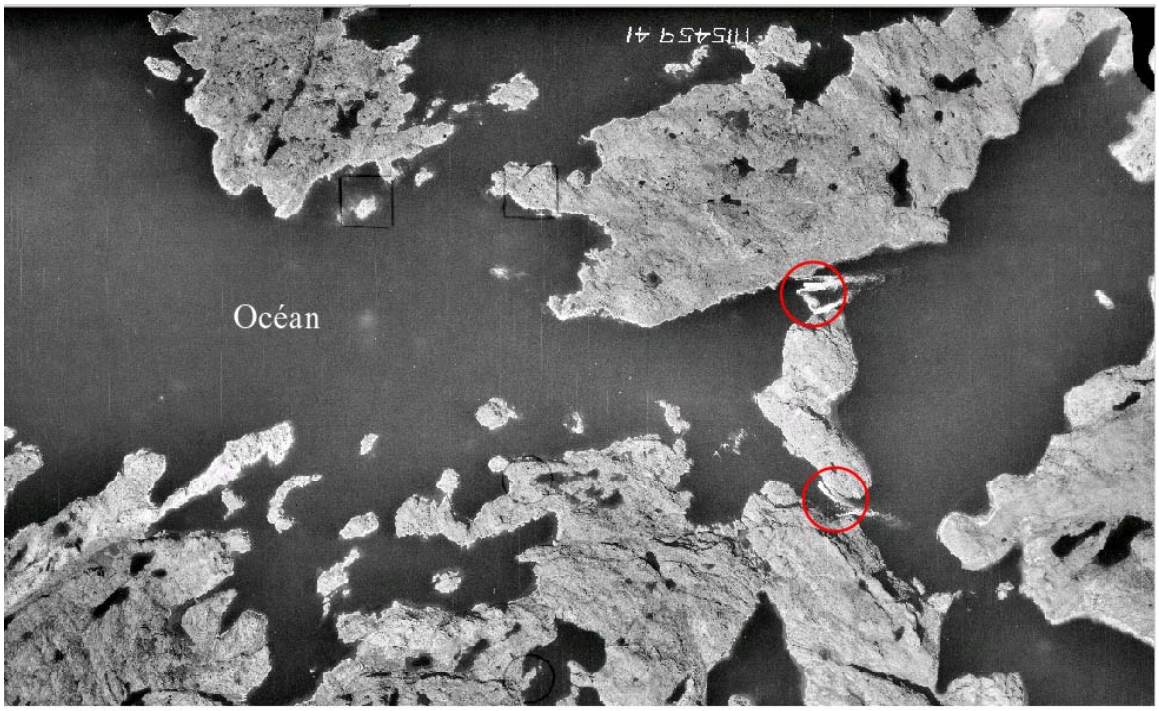
Source : photo HMQ98-134(91-92), échelle originale 1 : 15 000, carte 21E/12, 45° 36' N - 71° 32' O, rivière Saint-François à Bishopton (Québec) du 19-07-1998

Figure 10 : Stereoscopic example of specular reflexion on a portion of a watercourse (left photography) : this portion could be mistaken with a rapid



Source : photo HMQ98-134(91-92), échelle originale 1 : 15 000, carte 21E/12, 45° 36' N - 71° 32' O, rivière Saint-François à Bishopton (Québec) du 19-07-1998

Figure 11 : Stereoscopic example of specular reflexion on a portion of a watercourse (left photography) : this portion could be mistaken with a rapid



Source : CIT (Sherbrooke)

Figure 12 : Example of rapids caused by the tide in a rocky coastal shoreline environment. This type of periodic rapid (once or twice a day) is not represented on topographic maps.

10- Bibliography

Bravard, J.-P. et Petit, F. (2000) Les cours d ‘eau : dynamique du système fluvial. 2e édition, Armand Colin, Paris, 222 p.

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Mercier, D. (1988) Télé-interprétation de la dynamique fluviale par les méthodes analogique et numérique : application à la navigabilité sportive des cours d'eau. Mémoire de maîtrise, Département de géographie et télédétection, Université de Sherbrooke, 155 p.

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Provencher, L. et Dubois, J.-M.M. (2004a) Guide d’interprétation des entités géographiques naturelles à partir des images ETM+ de Landsat-7 : I – Fiche d’identification des entités géographiques naturelles. Ressources naturelles Canada, Géomatique Canada, Centre d’information topographique de Sherbrooke, Sherbrooke, 20 p.

Provencher, L. et Dubois, J.-M.M. (2004b) Guide d’interprétation des entités géographiques naturelles à partir des images ETM+ de Landsat-7 : II – Exemple de la fiche d’identification des eskers. Ressources naturelles Canada, Géomatique Canada, Centre d’information topographique, Sherbrooke, 51 p.

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.