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Regulations, legislation, and guidelines for artificial surface water and groundwater tracer tests in Canada

Christian Wolkersdorfer and Jenna LeBlanc

ABSTRACT

This paper describes Canadian federal and provincial regulations, legislation, and guidelines for artificial tracer tests, where substances are released into water, and provides a world-wide comparison. Alberta is currently the only Canadian province with guidelines and regulations relating to those tests. None of the other provinces have specific tracer test regulations in place, though the injection of artificial substances into waters is covered by Section 36(3) of the federal Fisheries Act. Newfoundland and Labrador, the Northwest Territories, and Nunavut sometimes require a permit to conduct a tracer test, and Quebec is planning to implement guidelines and regulations based on Michigan/USA Environmental Quality guidelines. In each case Fisheries and Oceans Canada (DFO), Environment Canada, and the Provincial environment departments should be contacted and the proposed test described as detailed as necessary. We present potential tracers, such as uranine (sodium fluorescein), or Rhodamine WT, that can be used in artificial tracer tests. This study is the result of contacting personnel from organizations such as Environment Canada, Fisheries and Oceans Canada, provincial departments of environment, researchers, and consultants.

Key words | artificial tracer tests, Canada, guidelines, legislation

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INTRODUCTION

Artificial tracer tests (sometimes referred to as tracer studies) are conducted to evaluate hydrogeological properties of aquifers or hydraulic parameters of surface streams and lakes as well as the marine environment (Käfl 1998). In order to conduct such an artificial tracer test, substances which are not yet present are introduced into the target water bodies. Some of those substances, if used in excess, might be harmful to the flora or fauna in the natural environment or to human health (Smart 1984; Field *et al.* 1995; Behrens *et al.* 2001).

It is therefore imperative that artificial tracers are regulated such that the water environment, wildlife, or human health is not negatively affected. Many countries regulate the use of artificial tracers by means of water legislation (e.g. European Union). In Canada, only a few of the provinces and territories have guidelines or regulations for tracer tests. This document describes information about guidelines and regulations of artificial tracer tests that

were collected from each province. We focused on non-radioactive tracers because radioactive tracers are thoroughly regulated by the radiation legislation and their use is typically restricted and regulated by the appropriate federal or provincial legislation.

In order to identify guidelines, regulations or legislation for artificial tracer tests in the Canadian provinces or territories, over 250 personnel from relevant Canadian organizations were contacted. Those include Environment Canada, Fisheries and Oceans Canada (DFO), provincial environment departments, the Canadian Environmental Assessment Agency and relevant consulting firms. Another 500 international colleagues from the International Mine Water Association (IMWA) were contacted to get an overview about international tracer test legislation. This document is an expansion of a previous web-based document, 'Artificial Tracer Test Legislation in Nova Scotia' (Wolkersdorfer 2011b), which only focused on the situation

in Nova Scotia. Much of the legal and regulatory information is only available on-line, possibly because regulations might change frequently. The paper therefore often refers to those on-line resources from numerous websites. Those documents are listed in the section Documents and Webpages at the end of the paper.

CLASSIFICATION OF TRACERS

Two types of tracers are commonly used to investigate hydrological properties: natural and artificial (Flury & Wai 2003; Leibundgut *et al.* 2009). Natural tracers are substances in the water or physico-chemical properties of the water that are naturally or accidentally present. An example of a 'naturally' present substance is the electrical conductivity which allows the effluent plume to be located within an exposure area. The environmental effects monitoring (EEM) Program for the metal mining sector (Environment Canada 2011), for example, recommends using this natural tracer. Examples of 'accidentally' occurring substances are tritium from atomic weapons testing, chlorofluorocarbons from refrigerators, krypton-85 release from nuclear fission (e.g. in power plants or spent fuel processing), or any other substance that becomes part of the water cycle after its unintentional release. Those tracers can be classified into environmental isotopes, environmental chemicals, organisms, and physical qualities of the water (Leibundgut *et al.* 2009). Artificial tracers are substances which are introduced into the water for detection elsewhere (generally downstream) in the system (Käsl 1998). They can be divided into two groups: water insoluble and water soluble tracers. Some examples of water soluble tracers are dyes or salts, and of water insoluble tracers are spores, bacteria, or microspheres (Käsl 1998).

Artificial tracer tests are commonly used in groundwater and surface water studies for determining hydraulic parameters. They are a means for determining such parameters as mass transfer rates, flow velocities, and flow paths of water and are also used in other fields of study such as: chemistry, physics, biology, geology, hydrology, engineering and water management (Käsl 1998, 2004). Very often, artificial tracer tests are essential for the protection and management of water bodies (Chave *et al.* 2006). They

might also be requested by legislators, an example in Canada being the environmental effects monitoring (EEM) Program. In the *2010 Pulp and Paper Environmental Effects Monitoring (EEM) Technical Guidance Document* (Environment Canada 2010), the use of a tracer is recommended in the receiving water, in order to delineate the effluent plume to assess the extent of an exposure area and in fishes, in order to make sure that these are truly exposed to a pulp or paper mill effluent.

Artificial tracer tests can also be used in mine water management projects. Not many results for tracer tests in flooded underground mines have been published so far. Yet, it has been shown that a tracer test can be a very practical method for planning remediation projects, finding connections between mines and the surface, investigating the reason for intrushes of mine water and assessing the effectiveness of bulkhead dams (Wolkersdorfer 2008).

IMPORTANCE OF GUIDELINES, REGULATIONS, AND LEGISLATION

Regulating the use of artificial tracers to maintain the quality of groundwater and surface water is exceptionally important (Holmbeck-Pelham *et al.* 2000). Generally, applying artificial tracers should be minimized and only the necessary amount of tracer that is needed to get positive results be used. Whenever possible, natural tracers should be given priority over artificial tracers. Also, artificial tracer dyes as a visual examination of the flow path should be excluded, because an excess use of tracer dyes can have long-term negative impacts on the environment and human health (Field *et al.* 1995). Such a negative effect occurred at a surface tracer test in the German Harz Mountains, where the injection of saturated NaCl brine caused the temporary withering of a tree and a mass killing of small red worms in the brook's sediment (Wolkersdorfer, unpublished). In addition, some of the tracers considered photosensitive (e.g. eosine, uranine), have shown a long-term stability when not affected by sunlight. Uranine's photodecomposition in real surface water bodies is not as severe as usually described (Tonogai *et al.* 1979). This is because the tracer is partly protected from photodegradation by a water column of at least a couple of centimetres. Therefore,

uranine can be used without difficulty for surface tracer tests with a duration of several hours. More specifically, uranine was still detectable 10 years after being injected into an abandoned German underground mine (G. Wirsing, pers. comm. 2000); even 2 years after injecting uranine into a Tyrolean underground mine shaft, the water was still coloured slightly green; 2 years after a tracer test in a Nova Scotian well, uranine could still be found in the well, and according to the Austrian Tracer Test Standard, artificial tracers can remain in the environment for several years (ÖWAV-Regelblatt 214, p. 3).

Many, but not all, of the commonly applied artificial water tracers are considered toxicologically safe. The toxicity of artificial tracers has been evaluated and published in several papers, such as Smart (1984), Field *et al.* (1995), and Behrens *et al.* (2001). In Behrens *et al.* (2001), 17 different water tracers were assessed for genotoxicity and ecotoxicity, and nine of them were considered safe (Table 1). Sulphorhodamine B was considered ecotoxicologically unsafe, rhodamine WT, rhodamine B and rhodamine 6G were not recommended, and lithium salts, strontium salts, bromides as well as activatable isotopes were considered safe with restrictions (Behrens *et al.* 2001). Substances, which are considered unsafe or unsafe with restrictions, should be regulated and managed such that the environment and human health is protected, and use of substances that are not recommended should be restricted in fresh or salt water. It should be noted here, that rhodamine WT (CAS [Chemical Abstracts Service Registry Number] 37299-86-8) is not on the 'Domestic Substance List' and based strictly on the Canadian Environmental Protection Act 1999 (CEPA 1999; Part 5: Controlling Toxic Substances), its use is not allowed in Canada without further approval. In the USA, rhodamine WT was removed from the 'Drinking Water Contaminant Candidate List' in 1998 (Flury & Wai 2003).

Many webpages and material safety data sheets as well as different publications (for references see Käß 1998) refer to uranine as being a 'biodegradable' dye tracer. Yet, as has been shown by Bottrell *et al.* (2010) and as suggested by the situations described above when tracer could still be seen years after its injection, uranine seems not to be significantly biodegraded under most conditions. The different, somehow inconsistent, information given so far might be an

indication that microorganisms catalyse the degradation of uranine only if another degrading chemical is in place, which has at least been shown for fluorescein (Itoh & Yatome 2004; Pirillo *et al.* 2010). Uranin's use as a 'visual' tracer should therefore be limited in the same way as for other artificial tracers and only the minimum amount of tracer be used to get positive analytical results.

During the writing of this paper there was a tracer study listed on the Kentucky Tracer test Notification webpage (<http://dep.gateway.ky.gov/dyetrace/ActiveDye-Trace.aspx>) which used the following tracers: Green (Uranine [Fluorescein] – Acid Yellow 73), Orange (Eosine – Acid Red 87), and Pink (SRB [Sulphorhodamine B] – Acid Red 52). Taking into consideration the ecotoxicological characteristic of Sulphorhodamine B, this shows that a regulatory framework or at least guidelines are necessary to ensure that potentially toxic tracers are used within the limits that are ecotoxicologically and environmentally save.

INTERNATIONAL TRACER TEST REGULATIONS

We contacted colleagues from 42 countries who are involved in water related research, consulting work, or administration and received replies from 32 countries. Amongst these are a little over a dozen countries that have some kind of tracer test regulation in place or at least the water acts can be applied to tracer tests. The results of our investigation are summarized in Table 2 and the details will be published in the journal *Mine Water and the Environment*.

In Europe the situation is based on EU water legislation (Water Framework Directive: Directive 2000/60/EC) and the national water legislation based on this EU law. Article 11(3)(j) prohibits the discharge of pollutants into groundwater but allows member states to authorize the injection of small amounts of substances for scientific purposes. Germany, for example, prohibits the use of naturally occurring water and the injection of substances into any kind of water body. Exceptions need an approval from the relevant authorities. Artificial tracer test permissions in Germany are based on procedures according to § 2 (1) and § 3 (1) No 5 of the German Water Budget Law. The water authority might permit those tests based on § 7(1) with conditions based

Table 1 | Overview of the toxicological assessment of 17 tracers (modified from Behrens *et al.* 2001, CAS numbers added for this paper)

Tracer	CAS-number	Toxicological assessment	Assessment basis
Uranine (sodium fluorescein)	518-47-8	Safe	T, L
Eosin yellow (Eosin Y)	17372-87-1	Safe	L, W
Sulphorhodamine B	3520-42-1	Ecotoxicologically unsafe	T
Amidorhodamine G	5873-16-5	Safe	T
Rhodamine WT	37299-86-8	Not recommended	T
Rhodamine B	81-88-9	Not recommended	T, L
Rhodamine 6G	989-38-8	Not recommended	T, L
Sodium naphthionate ^a	130-13-2	Safe	T
Pyranine	6358-69-6	Safe	T
Tinopal CBS-X ^b	38775-22-3, 27344-41-8 ^c	Safe	T
Tinopal ABP liquid	68155-70-4	Safe	T
Lithium salts	^d	Safe with restrictions	L, W
Strontium salts	^d	Safe with restrictions	L, W
Bromides	^d	Safe with restrictions	L, W
Activatable isotopes	^d	Safe with restrictions	L, W
Fluorescent polystyrene microspheres	9003-53-6 ^e or 9003-70-7 ^e	Safe	T, W
Spores of club moss dyed with acridine orange	–	Safe	T, W

Basis for toxicological assessment: T – toxicological tests; L – literature search; W – Working Group's expert judgement.

^aThe other sodium naphthionate has CAS number 28907-84-8, it is not obvious which one was used in each individual tracer test.

^bTinopal CBS-X (CAS 38775-22-3) is also sold as the disodium Tinopal CBS-X (CAS 27344-41-8).

^cSome suppliers list this substance with CAS 27322-41-8. Yet, this number has never been used by the CAS system.

^dDepends on salt used.

^ePolystyrene 9003-53-6, Polystyrene divinylbenzene 9003-70-7.

–: no CAS number.

on § 4(1) of the German Water Budget Law (see Wolkersdorfer 2008 for details). Currently, there is no approved procedure for the permitting process, but authorities commonly follow the Bavarian guidelines for artificial tracer tests (Schwarz *et al.* 2002) and the recommendations given in Käß (2004). In France by contrast, no special permissions are needed for scientific tracer tests.

In England and Wales groundwater tracer tests are controlled via the Environment Agency. This agency allows most groundwater tracer tests to be exempt from the need for a permit so long as these are registered with the Environment Agency and are able to fulfil certain criteria (details are given in Ward *et al.* 1998). For very low risk tracer tests there is also an exclusion from control (no need to register) in place which is limited by volume. A bespoke permit is required for groundwater tracer tests involving hazardous substances. All of this is controlled under the Environmental

Permitting (England and Wales) Regulations and the Horizontal Guidance H1 – Annex J 2 (Environment Agency 2012).

Austria, Switzerland, Slovenia, and Bavaria have the most comprehensive guidelines for conducting artificial tracer tests. These countries obtain a large quantity of drinking water from karstified areas and, historically, most of the tracer tests conducted in those countries were used to identify potential flow paths of groundwater in karst. Some of the recommendations in those guidelines form the basis for the discussion below.

Regulations in the USA are administered by the EPA's Underground Injection Control (UIC) program under the Safe Drinking Water Act (Code of Federal Regulations, Title 40, Parts 144–147), considering a tracer injection to be an 'experimental well' (Class V UIC well). In addition to EPA, each state has separate legislation and therefore

Table 2 | List of countries and their relevant tracer test guidelines, legislation or permitting procedure (based on an e-mail survey in October 2011); no: there is no known requirement; -: no information about requirements known

Country	Guidelines	Legislation	Permit	Remarks
Argentina	-	-	-	No information in the Environmental Impact Law for Mine Sites (national Law 24585: 'Additional Standards of the Environmental Protection Act for Mining')
Australia	No, but mentioned on Government Web Page	State dependent	Yes	Environment Protection Acts, Natural Resources Management Act; www.connectedwater.gov.au/framework/artificial_tracers.html
Austria	Yes	No	Sometimes	ÖWAV-Regelblatt 214
Belgium	-	-	-	
Bosnia-Herzegovina	-	-	-	
Brazil	-	-	-	
Chile	-	-	-	
Czech Republic	No	No	Yes	National Water Law: Zákon č.254/2001 Sb.; Zákon o vodách a o změně některých zákonů (vodní zákon)
England and Wales	Yes	Yes	Yes	Article 11(3) (j) of the Water Framework Directive (2000) and The Environmental Permitting Regulations 2010 (Environmental Protection, England and Wales 2010)
Estonia	-	-	-	
Finland	No	Yes	Yes	National Water Act (27.5.2011/587)
France	No	No	No	Loi n°2006-1772 du 30 décembre 2006 sur l'eau et les milieux aquatiques
Germany	In some states	Water Law	Yes	See text for details
Hungary	No	No	Yes	Environmental Protection Authority and the national health organization gives strict regulations for the concentration values of the applied tracer that field realization and detection of the tracer material are extremely difficult
India	No	No	No	Organizations conducting radiochemical tracer test for research purposes need to be registered with the Atomic Energy Regulatory Board (AERB) of India
Indonesia	No	No	No	
Ireland	No	No	No	Authorities and stakeholders must be informed
Italy	-	-	-	Some local recommendations and unpublished guidelines for speleologists exist
Morocco	-	-	-	
New Zealand	Part of	Yes Federal	Yes	The regulations relating to tracers are set by the regional councils
Peru	No	For radioactive tracers	for radioactive tracers	When radioactive tracers are used tracer test should be presented to nuclear energy national authority (IPEN); in general, tracer test should be presented to the National Water Association (ANA)
Poland	No	No	Yes	Water Framework Directive (2000)
Portugal	No	No	Yes	National Water Law

(continued)

Table 2 | continued

Country	Guidelines	Legislation	Permit	Remarks
Romania	No	No	No	Tracer test required for Drinking Water Zones (Romanian Ministry of Environment and Forests Ordinance no. 1278/2011)
Slovakia	No	No	Yes	Paragraph 18 of water law (no. 364/2004 Z.z.)
South Africa	No	No	Sometimes	Department of Water Affairs (DWA); based on National Water Act of 1998 (Act 36 of 1998)
Spain	No	No	Yes	'Confederaciones Hidrográficas' are responsible; in the CAPV (Comunidad Autónoma del País Vasco – 'Autonomous Region of the Basque Country') a Recommendation drafted by the Hydrogeology Research Group of the Basque Country University (UPV-EHU) for URA –Agencia Vasca del Agua, or 'Basque Water Agency': 'recopilación y homogeneización de información sobre ensayos con trazadores en la comunidad autónoma del país vasco. Propuesta para la regulación de su uso'
Sweden	–	–	–	If a tracer test is combined with test pumping then there might be a need of a water-rights judgement
Switzerland	Yes	No	Yes	Tracer announcement via national coordination centre; permission needed in some cantons; generally granted if conducted in accordance to national guidelines
USA	In some states	No	In most states	EPA UIC regulation under the Safe Drinking Water Act; variable legislation in individual states

rules can vary between states and from watershed to watershed, especially for surface water tracer studies. Some variations are now described briefly. Michigan, for example, authorizes all tracer dye studies through the Michigan Department of Environmental Quality (MDEQ 2010a). For tracer dyes which appear on the 'Acceptable Michigan Tracer Dye List' (MDEQ 2010b), a 'General Rule 97 Certification of Approval' is necessary, and tracer dyes not on this list require an 'Individual Rule 97 Certification of Approval' (MDEQ 2010a). A 'Notification of Intent' must be filled out and submitted to start the approval process (MDEQ 2010a).

In Kentucky, there are no regulations or required permits for tracer tests. However, they do have an online tracer dye notification system (DEP Department for Environmental Protection, Division of Water). This notification system allows users to submit notifications 24 hours a day and have access to a list of all tracer tests performed in the last 30 days (DEP Department for Environmental Protection, Division of Water). New Mexico incorporated the national standards into its groundwater regulations. At the

state level, the New Mexico Administrative Code regulations (20.6.2 NMAC) incorporate the national UIC program through the New Mexican Environment Department. As groundwater discharges are regulated, a discharge permit (sometimes temporary in nature for a test) would be issued if the tracer passed some threshold requirement for a discharge permit. Applicants need to file a notice of intent or discharge permit application to the relevant authority. Arizona has similar requirements to New Mexico, in that there is an Aquifer Protection Program within the Arizona Department of Environmental Quality where a permit is required, unless an exemption can be met (Arizona Revised Statutes Title 49, Chapter 2, Article 3 and Arizona Administrative Code Title 18, Chapter 9). In Colorado, the use of surface water or groundwater tracers at permitted mining sites must be approved by the state mining regulatory agency, which is the Division of Reclamation, Mining, and Safety. In addition, the operator must be able to verify that the activity will not degrade water quality. North Carolina uses an 'approved list of materials for injection' (before

using a substance listed in this North Carolina document, we recommend consulting [Table 1](#)).

In South Africa, the very progressive National Water Act (Act 36 of 1998) provides for so-called controlled activities to be regulated. This legislation allows the Minister to regulate activities having a detrimental impact on water resources by declaring them to be controlled activities. Section 37(1)(d) identifies intentional recharging of an aquifer with any waste or water containing waste as one such activity. Section 37(1)(e) is the 'catch-all' clause that merely requires an activity (e.g. artificial tracer testing) to have been declared a controlled activity by the Minister in order for it to be subject to this regulation.

RESULTS FOR CANADA

Legislation and regulations

From the majority of the responses received it is obvious that for most of the Canadian provinces no specific guidelines, regulations, or legislation for artificial tracer tests are in place ([Figure 1](#)). Section 36(3) of the Fisheries Act (R.S.C., 1985, c. F-14) is the only federal regulation that can be applied to tracer tests in Canada. This section is a general prohibition against releasing substances that may affect aquatic life and restricts the deposit of deleterious substances into waters (Fisheries Act R.S.C., 1985, c. F-14). In some circumstances, if a tracer is not on the 'Domestic Substance List' (DSL 1994) its use may be subject to the 'New Substance Notification Regulations' (Chemicals and Polymers) and 'New Substance Notification Regulations' (Organisms) under the Canadian Environmental Protection Act (S.C. 1991, c. 33). The objective of the DSL is to determine if a substance is new for the intent of the 'Canadian Environmental Protection' Act (S.C. 1991, c. 33). Regulations like those in the Fisheries Act can be found in the provinces. Ontario, for example, prohibits the discharge of any contaminant into the natural environment in Section 6(1) of the Environmental Protection Act (R.S.O. 1990, c. E. 19, last amended 2010). Similarly, the Ontario Water Resources Act (R.S.O. 1990, c. O.40, last amended 2011) states in Section 30(1) that a person discharging any material in water is guilty of an offence and according to

Section 5.3(1) of the New Brunswick Clean Environment Act (A.N.B. 1989, c. C-6.1, last amended 2011) 'no person shall release any contaminant or any class of contaminant into or upon the environment... unless that person is acting under and in compliance with authority or permission given under an Act of the Legislature'.

Alberta is the only province in Canada which regulates artificial tracer tests. Anyone who conducts an artificial tracer test has to follow the 'Code of Practice' and the 'Tracer Dye Study Guidelines' (Alberta Environment, Water Quality Branch Standards and Approvals Division 1991). Those guidelines explain the application procedure necessary to perform a tracer dye test, study considerations, procedure for informing the public, and reporting procedures. In addition, the 'Environmental Code of Practice for Hydrologic Tracing Analysis Studies' ([Government of Alberta 1996](#)) outlines the requirements which must be followed when conducting tracer tests in Alberta. The latter document results from the Substance Release Regulation (A.R. 124/93) under the authority of section 36 of the Alberta Environmental Protection and Enhancement Act.

Although there are no specific tracer test guidelines or regulations in place for Newfoundland and Labrador, the Northwest Territories, or Nunavut, persons conducting artificial tracer tests require a permit or a license. In Newfoundland and Labrador it is necessary to hold a permit from the local Fisheries and Oceans Canada office, but not necessarily from the Water Resources Division (Department of Environment and Conservation – Government of Newfoundland and Labrador). In the Northwest Territories a 'Scientific Research License' and a 'Type B Water License' (www.mvlwb.ca) is required. A type B water license permits the use of water or deposit of waste in water (Northwest Territories Water Act, 1992, c.39) and a Scientific Research License is required for all research in the Northwest Territories. This Scientific Research License can be obtained from the Aurora Research Institute (The Aurora Research Institute 1996; www.nwtresearch.com). Depending on the time needed to conduct the tracer test and the land needed, an additional 'Land Use Permit' may be required. A similar Research Permit is necessary in Nunavut, where the lead researcher needs permission from regional authorities and committees in order to conduct a research project according to the Scientist Act. Because

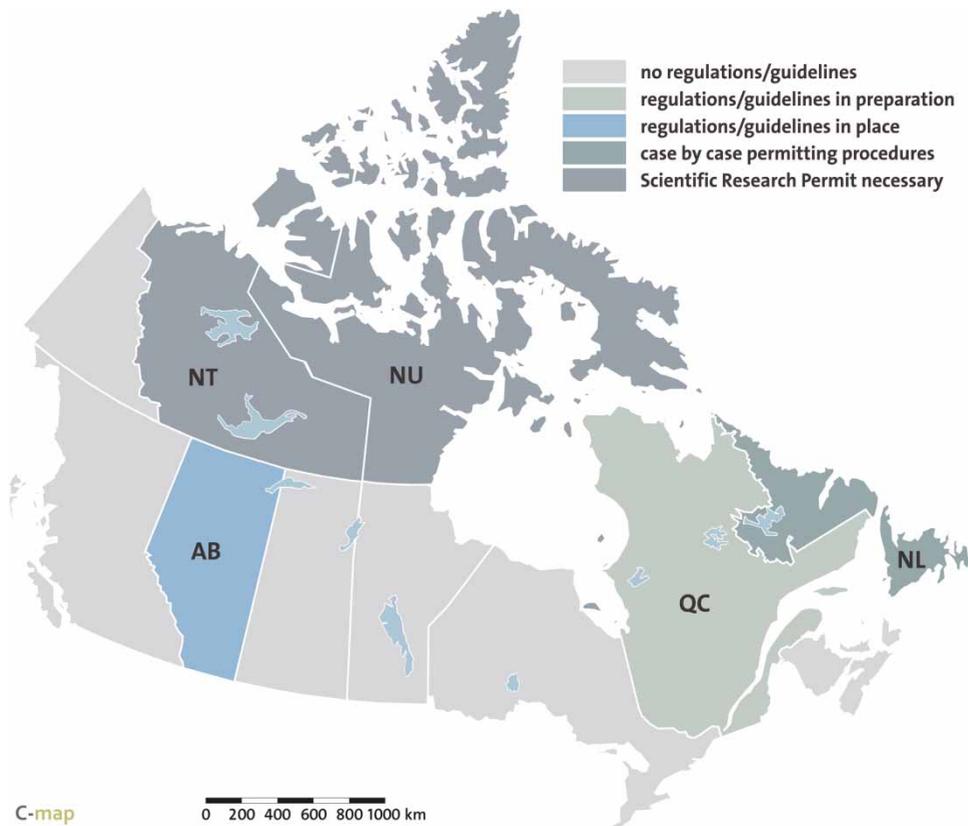


Figure 1 | State of tracer test regulations in Canadian Provinces and Territories.

the rules and regulations differ in the four Inuit regions (Inuvialuit Settlement Region, Nunavut, Nunavik, and Nunatsiavut) it is essential to contact the relevant region or the Nunavut Research Institute in Iqaluit.

Quebec has a variety of documents relating to surface and groundwater tracer tests, and a draft guideline for conducting such investigations ([Ministère du Développement durable, de l'Environnement et des Parcs 2010](#)). This draft guideline is based on the Michigan Department of Environmental Quality's guidelines ([MDEQ 2010a,b](#)). Within the draft guideline, an authorization process for approval to conduct a tracer test is described. A list of acceptable tracer dyes ([Table 3](#)) with a Final Acute Volume (FAV – Valeur aiguë finale à l'effluent; Quebec terminology: equal to the LD₅₀) in mg/L is included. Several very useful additional documents which contain information regarding tracer tests – not only beneficial for tracer studies in Quebec – have been produced by the Government of Quebec. They are described in the next section. All other

provinces and territories (British Columbia, Manitoba, New Brunswick, Nova Scotia, Ontario, Prince Edward Island, Saskatchewan and Yukon) currently have no specific regulations or guidelines for artificial tracer tests in place.

In summary, our investigations and electronic mail interviews showed two results:

- There is, even within the provinces, no uniform procedure for regulating or approving artificial tracer tests.
- Regulators, researchers and consultants desired that some kind of guideline or regulatory procedure was in place.

GUIDANCE DOCUMENTS

In addition to the Alberta guidelines for tracer tests, there are several Canadian guidance documents in place. One of those is the '2011 Metal Mining Environmental Effects

Table 3 | List of acceptable dye tracers. Adopted from Ministère du Développement durable, de l'Environnement et des Parcs (2010)

Product name	CAS number	Synonyms	FAV(mg/L)
Blue AZO Liquid	3844-45-9	Acid Sky Blue A, Blue 1206, Blue Dye, CI Acid Blue 9	12
Eosine Y	17372-87-1	Acid Red 87, Eosine, Eosine G, Eosine Sodium, Eosine YB, Eosine YS	7
Uranine (sodium fluorescein)	518-47-8	CI Acid Yellow 73, Fluorescein LT, Fluorescent LT, Fluoro Green 1234, Uranine	30
Lissamine Yellow FF	2391-30-2	CI Acid Yellow, Brilliant Sulphoflavine FF, Brilliant Acid Yellow 8G	200
Rhodamine WT	37299-86-8	Acid Red 388, FWT Red 200 ^a , FWT Red 25 ^a , FWT Red 50 ^a , Key Acid Rhodamine WT Liquid	13

FAV: final acute volume, equal to LD₅₀.

^aBright Dyes, the manufacturer of 'Fluorescent Red' dyes sells three different 'rhodamine type' dyes. Only the *liquid* sold under this brand name is rhodamine WT (CAS 37299-86-8, Acid Red 388); whereas the red dye powder sold under the same brand name is sulpho-rhodamine B (CAS 3520-42-1, Acid Red 52). They also sell 'Indust Red', which is rhodamine B (CAS 81-88-9, Basic Violet 10; pers. communication Bright Dyes – A Division of Kingscote Chemicals).

Monitoring (EEM) Technical Guidance Document' which includes recommendations for a 'Field Tracer Study' in the 'Additional Technical Guidance – How to Conduct Effluent Plume Delineation'. This document, meanwhile, has been updated and was published in 2003 (Murdoch *et al.* 2003). Though it is not specifically for artificial tracer tests in streams, it can be used as guidance document to some extent. Another guidance document was published by Environment Canada (2005). Yet, this one contains somewhat incorrect information about rhodamine WT and Na-fluorescein (they incorrectly refer to fluorescein instead of Na-fluorescein; the better term is uranine; see explanation regarding the terminology in Flury & Wai 2003 and Wolkersdorfer 2011a). Of the two, uranine should be the tracer of choice, not rhodamine WT, because uranine has a lower detection limit, it is less likely to adsorb to soil (Smart & Laidlaw 1977), and is less toxic than rhodamine WT (Field *et al.* 1995; Behrens *et al.* 2001; Käß 2004).

Quebec produced the document 'Outils de détermination d'aires d'alimentation et de protection de captages d'eau souterraine' (Rasmussen *et al.* 2006) which has a section on groundwater tracers. This section of the document suggests that the local health and safety services are contacted before a tracer test is performed and describes the backgrounds of groundwater tracers. Another document, 'Guide de Soutien Technique pour la Clientèle' (Direction des Politiques de l'Eau, Ministère du Développement durable, de l'Environnement et des Parcs, Direction des Politiques de l'eau 2011), describes how to perform flow measurements with the tracer dilution method. Further, the document 'Flow Measurements Methods in Open Channels' (Ministère du Développement durable, de l'Environnement et des Parcs 2010) describes flow measurements with the tracer dilution method and the travel time technique.

Fisheries and Ocean Canada (DFO) has an on-line flow chart for works that will be conducted near water (www.dfo-mpo.gc.ca/habitat/habitat-eng.htm). It describes that there should be three steps considered: Follow Planning Guidance, Project Review, and if necessary Authorization Process. Because no planning guidances for artificial tracer tests are in place, DFO recommends submitting a project proposal for review and assessment. The 'Proponent's Guide to Information Requirements for Review Under the Fish Habitat Protection Provisions of the Fisheries Act' (Version 1.2, April 2009) is a 12-page document and includes recommendations for work in and at water courses.

In the following section, we recommend how the Canadian provinces might handle the approval of artificial tracer tests without creating unnecessary hurdles for the hydro (geo)logists and legislators involved.

DISCUSSION AND RECOMMENDATIONS

As outlined above, except for Alberta, there are no set guidelines or regulations for artificial tracer tests for Canadian provinces or territories in place (Table 4). Newfoundland and Labrador, the Northwest Territories, and Nunavut have a case-by-case process for tracer tests and Quebec has a draft version of guidelines. Usually, three authorities should be contacted when planning to conduct an artificial tracer test:

Table 4 | Summary of Canadian provincial and federal regulations relating to tracer test studies

Province	Regulations	Remarks
Alberta	Yes	Tracer-Dye Study Guidelines Environmental Code of Practice for Hydrologic Tracing Analysis Studies
British Columbia	No	Consult British Columbia Field Sampling Manual for sampling (nothing about tracer tests)
Manitoba	No	Non-deleterious substances thus protecting groundwater, surface water, and soil integrity must not be permitted
New Brunswick	No	Inform Department of Environment
Newfoundland and Labrador	Part of	Permit from the local Fisheries and Oceans Canada, case based, no printed guidelines
Northwest Territories	Part of	Type B water license and a Research License; land use permit might be necessary
Nova Scotia	No	Fisheries and Oceans Canada, Environment Canada, Provincial environment departments
Nunavut	Part of	Research permit necessary
Ontario	No	Contact Ministry of Environment
Prince Edward Island	No	Inform Department of Environment, Energy and Forestry
Quebec	Draft version	Based on the Michigan Department of Environment Process for obtaining authorization to use tracer dyes; several good guidance documents
Saskatchewan	No	–
Yukon	No	If tracer is considered a waste, license is required
Federal Canada	Indirect	Through Fisheries Act in Section 36(3)

- Fisheries and Oceans Canada (DFO)
- Environment Canada
- Provincial environment department.

These three authorities should be notified of the tracer test purpose and be given details on the tracer test. In order to provide essential information about the planned tracer test, we recommend provision of the following information (adopted after [Wolkersdorfer 2008, 2011b](#)):

- District and place name including map and map references
- Person responsible for conducting the tracer test and contact phone numbers
- Customer with full address
- Purpose of the tracer test
- Type of tracer with its exact name, CAS number (Chemical Abstracts Service Registry Number), expected dilution, LD₅₀ (50% lethal dose) data and MSDS sheets
- Description of injection sites including map
- A list of sampling sites including map and sampling intervals
- Water quantities to flush the injection site and the tracer including where water will be drawn from

- Start of tracer test including start and end of tracer injection
- Work schedule for continuous sampling
- Necessary measurements on site
- Work schedule for analytical laboratory
- Emergency plan including contact phone numbers.

Tracer tests conducted in the vicinity of areas where potable water is produced need a careful selection of the tracer substance. Therefore, besides consulting [Tables 1 and 3](#) for a selection of potential tracers, the ‘NSF/ANSI STANDARD 60 – Drinking Water Treatment Chemicals – Health Effects’ might be consulted when conducting a tracer test within a drinking water zone. This standard lists NSF (National Science Foundation) certified tracer dyes used in drinking water treatment and their maximum recommended concentration in drinking water (www.nsf.org/Certified/PwsChemicals). NSF, according to their web page, certifies chemicals ‘to ensure that these products do not contribute contaminants to drinking water that could cause adverse health effects’ and this standard is used in nine Canadian provinces (2006 data in [NSF International 2010](#)).

Also, we recommend that any persons who wish to perform a tracer test should use the Efficient Hydrologic

Tracer-Test Design (EHTD) computer program to estimate the amount of tracer mass which is necessary to get good results. The document ‘Tracer-Test Planning using the Efficient Hydrologic Tracer-Test Design Program’ (Field 2003) can be used as a guideline for anyone who plans to use the EHTD program. We also encourage everybody who conducts a tracer test to limit the tracer amount to a minimum as tracers might be stable under certain environmental conditions and can interfere with future tracer studies. In addition, researchers, consultants, and manufacturers should give precise information about the tracers used. There are, for example, many different rhodamines with varying physical and chemical as well as ecotoxicological behaviour. Specifications such as ‘a rhodamine type tracer’ or ‘xanthene dye form’ are not necessarily helpful for scientific purposes.

Furthermore, the public involvement guidelines in ‘Tracer-Dye Study Guidelines’ (Alberta Environment, Water Quality Branch Standards and Approvals Division 1991) should be followed. This guideline explains that it may be necessary to arrange public meetings to inform the public of the tracer dye test to be performed and answer any questions or concerns. The pollution control office should also be notified at least 48 hours before the tracer test is performed. Depending on the location of the tracer dye test, all licensed water withdrawal users may need to be notified before the test (Alberta Environment, Water Quality Branch Standards and Approvals Division 1991). Very valuable information about preparing and conducting artificial tracer tests can also be obtained from the recommendations published by the Québec Government (see descriptions above).

Finally, as observed in Austria, Bavaria, Switzerland, and Kentucky, a tracer test database should be set up. This database would be helpful for researchers when conducting a tracer test, as they could plan their tracer test based on existing studies in the area. In addition, background concentrations of the tracers used could be explained if the database lists a tracer test recently conducted in the study area.

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DOCUMENTS AND WEBPAGES

This non-comprehensive list of documents can be used as guidance documents in those Canadian Provinces where currently no other guidelines or regulations are in place. It also lists references to federal or provincial acts cited in the text. All web pages are current as of 2011-11-18. They should be double checked with an internet search engine if a dead link is encountered. Some files are also available as electronic supplements to this paper on the author's web page (www.wolkersdorfer.info/tracerlegislation).

Alberta

Tracer-dye study guidelines

<http://environment.gov.ab.ca/info/posting.asp?assetid=5885&categoryid=5>

Environmental Code of Practice for Hydrologic Tracing Analysis Studies
www.qp.alberta.ca/508.cfm

Ontario

Environmental Protection Act (R.S.O. 1990, c. E.19)

s. 6(1): 'No person shall discharge into the natural environment any contaminant, and no person responsible for a source of contaminant shall permit the discharge into the natural environment of any contaminant from the source of contaminant, in an amount, concentration or level in excess of that prescribed by the regulations'.

www.e-laws.gov.on.ca/html/statutes/english/elaws_statutes_90e19_e.htm

Ontario Water Resources Act (R.S.O. 1990, c. O.40)

s. 30(1): 'Every person that discharges or causes or permits the discharge of any material of any kind into or in any waters or on any shore or bank thereof or into or in any place that may impair the quality of the water of any waters is guilty of an offence'.

www.e-laws.gov.on.ca/html/statutes/english/elaws_statutes_90o40_e.htm

Northwest Territories

Northwest Territories Waters Act

<http://laws-lois.justice.gc.ca/eng/acts/N-27.3>

Northwest Territories Waters Regulations

<http://laws.justice.gc.ca/eng/regulations/SOR-93-303>

Nova Scotia

Artificial Tracer Test Legislation in Nova Scotia (Wolkersdorfer 2011)

www.wolkersdorfer.info/publication/pdf/TracerTestLegislationNovaScotia.pdf

Quebec

Note d'information sur les traceurs environnementaux

Traceurs environnementaux.docx (electronic supplement)
Guide de soutien technique pour la clientèle règlement sur la déclaration des prélèvements d'eau

www.mddep.gouv.qc.ca/eau/prelevements/index.htm

Outils de détermination d'aires d'alimentation et de protection de captages d'eau Souterraine

www.mddep.gouv.qc.ca/eau/souterraines/alim-protec/index.htm

Outils de détermination d'aires d'alimentation et de protection de captages d'eau Souterraine: ANNEXE A – Données existantes

Outils-annexes.pdf (electronic supplement)

Sampling Guide for Environmental Analysis – Booklet 7 – Flow Measurement Methods in Open Channels www.ceaeq.gouv.qc.ca/documents/publications/echantillonnage/debit_conduit_ouv_C7_ang.pdf

Canada

Metal Mining Effluent Regulations (SOR/2002-222)

www.laws-lois.justice.gc.ca/eng/regulations/SOR-2002-222

Field Tracer Study

www.ec.gc.ca/eseec-eem/default.asp?lang=En&n=E93AE5BC-1&offset=2&toc=show#Tracer

The Living Water Policy Project

www.waterpolicy.ca

Fisheries Act (R.S.C., 1985, c. F-14)

<http://laws-lois.justice.gc.ca/eng/acts/F-14>

Proponent's Guide to Information Requirements for Review Under the Fish Habitat Protection Provisions Of the Fisheries Act Version 1.2 April 2009 (DFO/2007-1157)

www.dfo-mpo.gc.ca/habitat/role/141/1415/14155/requirements-exigences/index-eng.asp

Domestic Substance List DSL 1994

www.ec.gc.ca/lcpe-cepa/default.asp?lang=En&n=5F213FA8-1

New Substances Notification Regulations (Chemicals and Polymers; SOR/2005-247)

www.ec.gc.ca/lcpe-cepa/eng/regulations/detailReg.cfm?intReg=92

NSF certified products

www.nsf.org/Certified/PwsChemicals

Pulp and Paper Technical Guidance

The objective of these documents is to solely provide guidance to the regulated industry (Pulp and Paper and Metal Mining) on how to meet the environmental effects monitoring regulatory requirements prescribed respectively under the Pulp and Paper Effluent Regulations and the Metal Mining Effluent Regulations. The intent of these documents is not to recommend the use of any chemical substance as artificial tracers but to provide technical guidance to the regulated industry and therefore, should not be treated as legal interpretation of the regulations (pers. comm. National Environmental Effects Monitoring Office Bureau national des études de suivi des effets sur l'environnement 2011)

www.ec.gc.ca/esee-eem/default.asp?lang=En&n=A2-CA9EEF-1

International*Austria: Tracer Test Database*

www.lebensministerium.at/wasser/wasser-oesterreich/wasserkreislauf/hydrographische_daten/Markierungsversuche_GW.html

Austria: ÖWAV-Regelblatt 214 (Markierungsversuche in der Hydrologie und Hydrogeologie [Tracer Tests in Hydrology and Hydrogeology])

<https://www.astandis.at/shopV5/search/Details.action?dokkey=265492>

Switzerland: Einsatz künstlicher Tracer in der Hydrogeologie – Praxishilfe [Utilisation des traceurs artificiels en hydrogéologie – Guide pratique]; [Use of Artificial Tracers in Hydrogeology – Practical Advice]

www.bafu.admin.ch/publikationen/publikation/00439 (also available in French); English version: Schudel B., Biaggi D., Dervev T., Kozel R., Müller I., Ross J.H. & Schindler U. 2003 Application of artificial tracers in hydrogeology – Guidelines. Bulletin d'Hydrogéologie 20, Special Issue.

Bavarian guidelines for artificial tracer tests (Schwarz et al. 2002)

Hinweise für die Durchführung und die Begutachtung von Markierungsversuchen in Gewässern – Merkblatt Nr. 3.1/1 vom 6.6.2002

Hinweise für die Durchführung und die Begutachtung von Markierungsversuchen in Gewässern.pdf (electronic supplement)

European Union Water Framework Directive: Directive 2000/60/EC

Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy:

'Article 11(3)(j) ... Member States may authorize ... [d]ischarges of small quantities of substances for scientific purposes for characterization, protection or remediation of water bodies limited to the amount strictly necessary for the purposes concerned provided such discharges do not compromise the achievement of the environmental objectives established for that body of groundwater'

<http://ec.europa.eu/environment/water/water-framework>

United States Underground Injection Control Program

<http://water.epa.gov/type/groundwater/uic>

United States Geological Survey

Office of Surface Water Technical Memorandum No. 86.08: Programs and Plans – Dyes for Water Tracers (maximum concentration for Rhodamine WT near water intakes shall not exceed 10 µg/L).

<http://water.usgs.gov/admin/memo/SW/sw86.08.html>

Michigan: MDEQ Process for Obtaining Authorization to Use Tracer Dyes

www.michigan.gov/deq/0,1607,7-135-3313_46123_54919-227024-,00.html

North Carolina: List of Approved Injectants

MS Excel File containing substances that have met regulatory requirements for use with injection wells. List is updated as new injectants are approved for use.

http://portal.ncdenr.org/c/document_library/get_file?uuid=f0c4520b-a93d-4b0d-92ab-098e5650f18e&groupId=38364