Practical Paper

A practical decision tree tool that water utilities can use to solve taste and odor problems

Michael J. McGuire, Ruth Hund and Gary Burlingame

ABSTRACT

Much research has been performed into the science of aesthetic water quality, but utilities have had difficulty incorporating this science into their practices. A decision tree was developed that, for the first time, provides a resource that utility professionals can use to describe an off-flavor, determine the origin, quickly learn how to proceed with an investigation of the off-flavor event and identify potential solutions. Utility personnel can quickly learn how to be detectives for their systems without the training necessary to be experts. If the electronic decision tree does not lead to resolution of the taste and odor problem, then the utility professional, who was not previously knowledgeable in off-flavors, can have a productive discussion with an expert regarding tastes and odors. Communicating the lessons learned by the scientists of aesthetic water quality to the utility professionals in a quick and easy manner will lead to more resolved taste and odor events and better water quality.

Key words | decision tree, distribution system, off-flavors, source of supply, taste and odor, water treatment plant

Michael J. McGuire (corresponding author)
Ruth Hund
McGuire Malcolm Pirnie,
1919 Santa Monica Blvd., Suite 200,
Santa Monica, CA 90404,
USA
Tel: +1 310 829 1441
Fax: +1 310 829 2155
E-mail: *mmcguire@pirnie.com*

Gary Burlingame
Philadelphia Water Department,
3427 Decatur Street,
Philadelphia, PA 19136-3023,
USA

INTRODUCTION

A great deal of research has been completed in the identification and control of off-flavor problems. Water utilities know that they have to integrate this knowledge so that they can understand and control tastes and odors. Their customers demand that off-flavors are controlled since the public generally associates off-flavors with possible health and safety issues (McGuire 1995). Much of the literature is based on case studies and descriptions of how a particular taste and odor event is resolved. However, the utility professional who is not trained in the science of off-flavors does not know where to begin an investigation into a taste and odor event. Some compendiums of off-flavor information have been published and various articles on how to investigate taste and odor events appear in the literature, but they are so voluminous that utility professionals do not have the time or staff either to understand or to make practical use of these materials. In order for a utility to effectively address taste and odor problems, existing research must be evaluated, taste and odor problems must be prioritized, their most likely causes must be determined, and only then should the most likely solutions or control strategies be implemented.

McGuire Environmental Consultants and the Philadelphia Water Department, under an AWWA Research Foundation (AwwaRF) contract, developed a taste and odor decision tree that guides utilities to efficiently resolve taste and odor events. A workshop was held in Denver, Colorado with experts in utility management, off-flavor identification, off-flavor control strategies and communications to refine the decision tree. Experts established a hierarchy of the most common off-flavors, their most likely causes and their most effective solutions. The decision tree presents these findings in a systematic way that can be used

by researchers, utility managers, laboratory personnel and water treatment plant operators. The decision tree was published in the report entitled "*Water Quality Self-Assessment for the Management of Aesthetic Issues*" with a CD-ROM entitled "*A Self Assessment and Decision-Tree Tool for Taste and Odor*" (McGuire *et al.* 2004).

DEFINITIONS

What is a decision tree? A decision tree is an organized list of questions with guidance and references that leads the user through a series of decisions to a logical endpoint that results in the solution to a problem. Expert systems and neural networks are other terms and methodologies for arriving at the same destination, which has been mapped out in this project for the taste and odor decision tree.

In order to develop a decision tree, or expert system, definitions of a taste and odor event and an off-flavor needed to be established. These definitions were created for this project and have not been previously published. They can be interpreted as a standard or goal of the water industry:

- Off-flavor: An off-flavor is an observation by consumers or experts that a flavor (a taste, odor or mouth feel sensation) exists in a water sample that is not normally present and constitutes an unusual or offensive perception.
- Taste and odor event: A taste and odor event is the occasion when a utility is aware of an off-flavor in the drinking water. An event may be as small as one customer that is displeased with the flavor of the water or as large as a system-wide event. The event may be discovered by a customer complaint, an early warning system in the sources of supply (McGuire *et al.* 1983), a water treatment facility operator or sensory analysis panel.

A utility's ability to manage these events system-wide, from the source water to the customer's tap, is an indication of its ability to manage water quality changes in the source water, at the treatment plant and in the distribution system. Off-flavors are often detected by consumers at the ng/L level, near or below the detection limit of many analytical techniques commonly used in the water utility community (Izaguirre *et al.* 1982). They can be due to virtually any change in the system including the source water, chemical feed systems, chemical dosing, pH control, changes in the distribution system operation or biological growth. If a utility is able to control contaminants in its drinking water to the ng/L level, then the utility will generally be able to control the majority of taste and odor events.

The goal of preventing the occurrence of all off-flavors in drinking water as perceived by the customer is virtually impossible to meet. Nonetheless, it is important to strive for this goal. Providing water that is free of off-flavor problems goes beyond the minimal goal of meeting secondary drinking water regulations in the USA.

The decision tree is based on the user's understanding of both the sensory descriptor and the origin of the off-flavor. Sensory descriptors used in the decision tree match the taste and odor wheel for drinking water (Mallevialle & Suffet 1987), although there are some notable exceptions, such as cat urine and kerosene. If the user knows either a sensory descriptor or the chemical, but not both, then the comprehensive table of chemicals, sensory descriptors and odor threshold concentrations developed for the project and provided in the decision tree will be helpful. The ability to control off-flavors often hinges on the identification of the problem-causing compounds, which are often first identified through the use of sensory descriptors (McGuire & Gaston 1988).

One of the first questions asked in the decision tree is with regards to the origin of the off-flavor. Each component of the drinking water system is described in Table 1.

PROTOCOL FOR RESOLVING TASTE AND ODOR EVENTS

The decision tree is, in part, a protocol for resolving a taste and odor event. In various forms, taste and odor experts around the world have followed this protocol for decades – consciously or unconsciously. Only a few experts dedicated to the field have the comprehensive knowledge required to resolve taste and odor events. To gain enough expertise to resolve a wide variety of aesthetic events, one needs to read a substantial body of literature, much of it anecdotal, and gain expert contacts.

Table 1 | Definition of the components of drinking water systems used to characterize taste and odor events

Components of a drinking water system	Definition
Customer infrastructure	Piping (plumbing) and storage that is typically beyond the customer's water meter: includes pipes, water heaters, point of use devices, and icemakers
Distribution system	Piping, storage facilities and booster facilities between the water treatment facility and the beginning of the customer infrastructure
Water treatment facility	All equipment located between the plant influent and the distribution system. Water treatment facilities can be as minimal as a chlorination facility and a pump or as complicated as a multi-stage treatment plant with advanced water treatment processes such as ozone and membranes
Source	Groundwater or surface water prior to treatment, disinfection and distribution

Many utility personnel do not know what questions to ask to begin solving an off-flavor problem. This decision tree and the underlying decision/action protocol are now available in a written format, and they provide the fundamentals to enable utility personnel to resolve their own taste and odor events. If the staff is unable to resolve the problem, they can contact an expert and have a discussion clearly focused on identification of the problem and its solution. The protocol for resolving taste and odor events is outlined below:

1. Communicate with stakeholders.
2. Verify event.
3. Communicate with stakeholders.
4. Determine origin and character of off-flavor.
5. Communicate with stakeholders.
6. Determine cause of off-flavor.
7. Determine and implement control strategy.
8. Communicate with stakeholders.

The next section walks through the identification and resolution of a taste and odor problem using this protocol. The protocol clearly shows the importance of communication with the utility's stakeholders. Communication should be included throughout a taste and odor problem resolution to properly manage a taste and odor event. While each of these communication steps has different aspects, each step shares several key elements. Each communication step requires the identification of the appropriate stakeholders, development of the appropriate messages for those stakeholders and determination of the appropriate vehicle(s) to send those messages. Examples of communication vehicles used to carry the utility's message include: press releases sent to the media, paid advertisements in newspapers, public service announcements distributed to local television stations, in-house newsletters distributed to customers, presentations by speaker's bureau members and bill inserts. Each communication step should be outlined in a strategic communication plan. The communication plan should be in written form and address both internal and external audiences.

The internal component of a strategic communication plan details the flow of information through the organization and identifies the roles of the appropriate personnel in various situations, ranging from uneventful operations to a significant crisis. A key element of this plan should include the identification of trained spokespersons and the development of messages specific to an aesthetic event.

All personnel who may come into contact with stakeholders, from the general manager to the meter reader, should understand the organization's messages to its stakeholders. For example, it is important that the conversation a valve crew supervisor has with a passer-by while fixing a water main reflects the same message the local newspaper published based upon an interview with the water quality director. A consistent message creates trust and goodwill between the utility and the community it serves.

The first step in developing the external component of the communication plan is to identify the stakeholders. Examples of stakeholders include customers, electronic and print media, policy makers, regulators, suppliers and key community leaders. The second step is to identify key messages for all stakeholders. Finally, the strategies and tactics for implementing the plan must be determined. These strategies may include stakeholder involvement,

community involvement, web site communications, media communications and communications on a regular basis with stakeholders concerning utility issues. The utility's external communication plan should detail the goals, stakeholders, messages, strategies and tactics to be used to discuss the aesthetic quality of the water with the media, consumers, governing boards and other interested stakeholders. The plan should include scenarios of periodic communication and various crises, such as aesthetic events.

All communication steps in the taste and odor management protocol (e.g. proactive communication following verification of an off-flavor, the identification of the off-flavor and its source and resolution of the event) should be outlined in the strategic communication plan. The plan should be written, practiced and implemented.

EXAMPLE: EARTHY-MUSTY ODOR SCENARIO

The decision tree is a program written in HTML and JavaScript languages that branches out quickly and is not easily represented in a technical paper. However, a description of how a user may apply the decision tree to resolve a hypothetical situation, such as a complicated earthy-musty odor problem in surface water, is outlined below.

A surface water utility receives several complaints from consumers of an odor described as "dirty" or "moldy" in a number of households far from the treatment plant. The same treatment plant serves all of the households. The utility's water quality director (WQD) is caught off-guard because her water utility has never had a taste and odor problem in this water source. However, the WQD has a copy of the Taste and Odor Decision Tree on CD ROM and refers to it for guidance. The first question on the decision tree is whether or not the utility has a strategic communication plan (Figure 1). If one is available, the WQD is reminded to use it; if not, some guidance is given on how to develop a strategic communication plan.

The next few questions in the decision tree assess whether or not the WQD is able to identify the source and characteristic of the problem by either chemical or sensory methods (Figure 2). If the WQD is unable to identify either the source or character of the odor, the decision tree leads the WQD to a series of explanations and references. Without knowing what the odor is or the origin, the WQD can only guess what the problem is and begin to randomly evaluate potential solutions for an undefined problem.

The next page of the decision tree asks the WQD to verify the origin of the event. This involves going to several of the households that have complained to ensure that there is indeed an off-flavor. A sample should be collected and returned to the laboratory for further analysis. During this verification step, information on the timing of the appearance of the off-flavor should be obtained. Once the off-flavor is verified, the utility should communicate with households in the area and let them know that a problem exists.

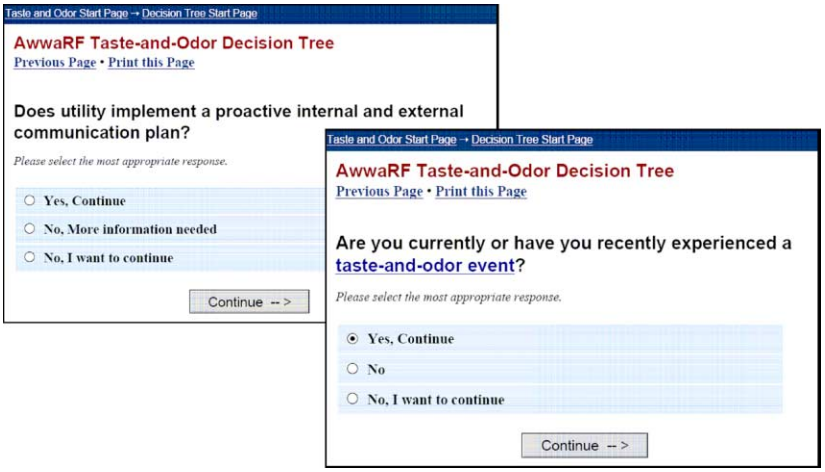


Figure 1 | Decision tree screens to determine if a communications plan and a taste and odor problem exists.

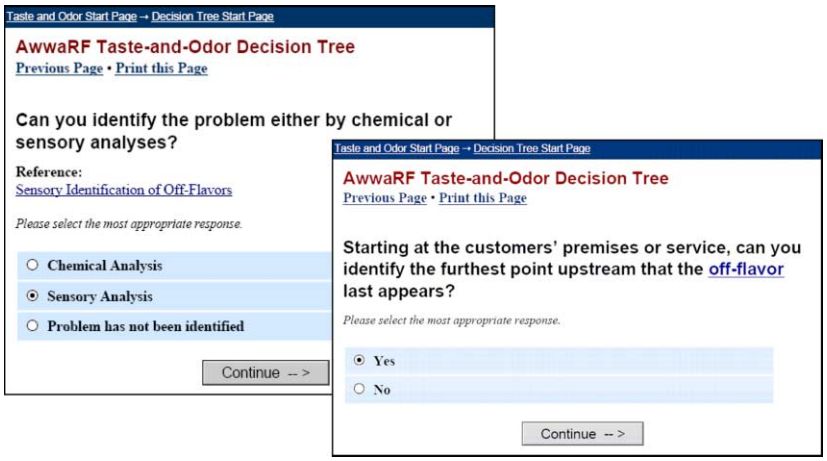


Figure 2 | Decision tree screens assessing how much is known about the problem.

The samples returned to the laboratory are evaluated either by Flavor Profile Analysis (FPA) or geosmin and 2-methylisoborneol (MIB) analyses (Krasner *et al.* 1983 1985), which may be sent to an FPA panel or contract laboratory, respectively. The taste and odor whefel identifies dirty or moldy odors as most likely caused by geosmin and MIB (Mallevialle & Suffet 1987); therefore, the samples will be analyzed for these compounds. With confirmation of the odor event, samples are then collected first at the households, then throughout the distribution system and the water treatment plant, and finally from the source of supply. In this example, samples confirmed that the earthy-musty odor problem was caused by 20 ng/L of MIB, which was produced in a large source water reservoir on the Colorado River (Figure 3).

Knowing these two critical pieces of information, i.e. the character and origin of the off-flavor, the utility personnel can begin to take action toward resolving the problem. The next few screens in the decision tree summarize the problem and identify potential solutions (Figure 4). If none of the listed solutions solves the problem, the user is directed back to the point in the decision tree where the origin and character of the odor are determined. In our example, the problem was traced to an attached blue–green algae bloom in the source water

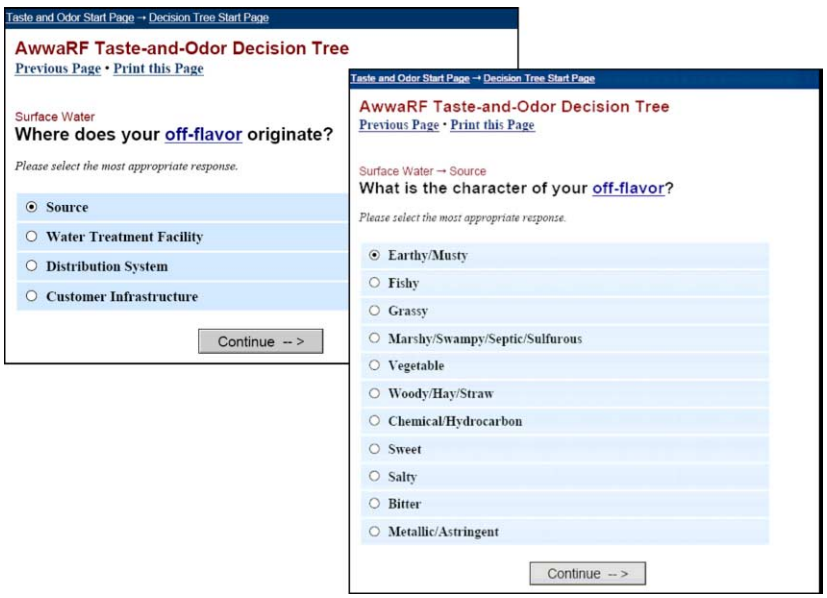


Figure 3 | Decision tree screens identifying the source and character of the problem.

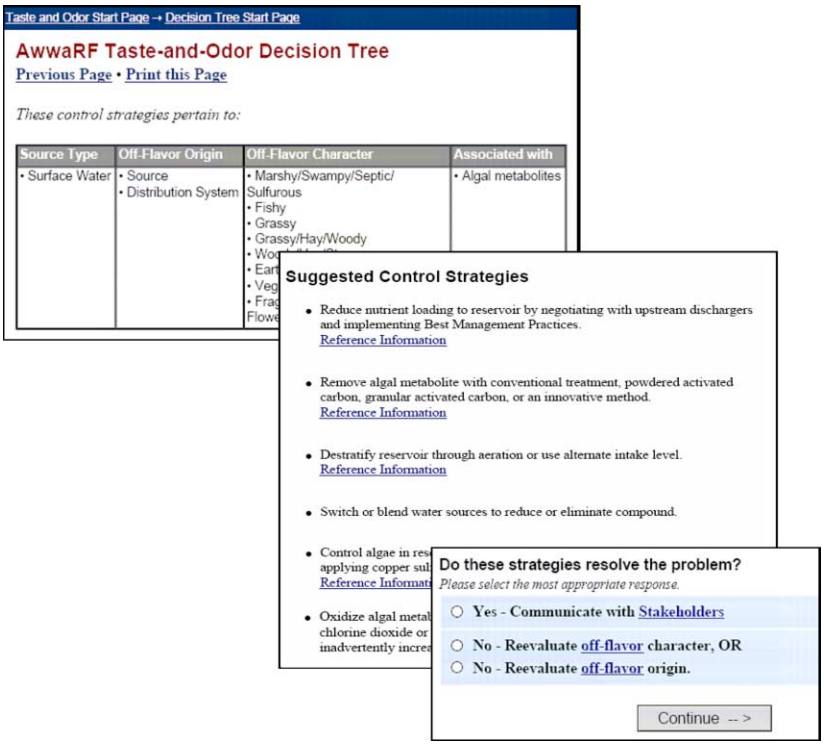


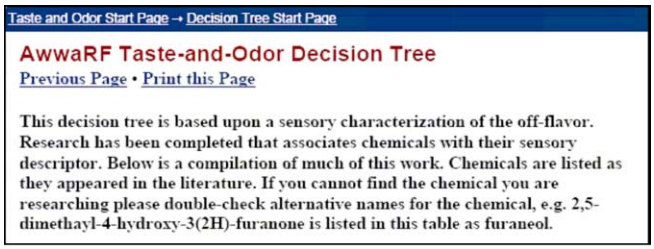
Figure 4 | Decision tree screens identifying the potential solutions to the problem.

reservoir. Switching to another source of supply solved the problem.

Once the problem is resolved, the WQD is reminded by the decision tree to communicate with the stakeholders. The affected households need to know that the problem has been resolved. Providing this information is an element of good customer service and helps the customer feel valued. In the future, MIB mitigation may require significant capital and operations expenditures. Customers, governing boards and the media need to be informed that their money was spent wisely and the problem was resolved.

ODOROUS CHEMICALS, ODOR AND TASTE THRESHOLD CONCENTRATIONS AND SENSORY DESCRIPTORS

A table of off-flavors, odor and taste threshold concentrations, and sensory descriptors was assembled as part of the development of this taste and odor decision tree. This table can be found in the CD ROM accompanying the "*Water Quality Self-Assessment for the Management of Aesthetic Issues*" AwwaRF Report. Although FPA is an established method, sensory descriptors related to specific organic compounds, odor threshold concentrations (OTCs) and taste threshold concentrations (TTCs) are often not well-defined. OTC and TTC values for the same chemical compound in the summary table vary widely depending on the number of panelists, panelist training, sample temperature, method of sample presentation (e.g. forced-choice triangle) and calculation procedure. Over 300 chemicals and descriptors are listed in the OTC/TTC table on the CD ROM. This table will be useful to utility personnel who are trying to link a particular problem identified by a sensory characteristic (e.g. medicinal odor) with potential chemical causes (e.g. chlorophenols, decanal or 4-iodophenol). Figure 5 includes 2 of the 300 chemicals from the table to illustrate the OTCs and TTCs for 2-methylisoborneal and geosmin (i.e. earthy-musty sensory descriptor) as reported by various studies and summarized in the decision tree.



Taste and Odor Start Page → Decision Tree Start Page

AwwaRF Taste-and-Odor Decision Tree

Previous Page • Print this Page

This decision tree is based upon a sensory characterization of the off-flavor. Research has been completed that associates chemicals with their sensory descriptor. Below is a compilation of much of this work. Chemicals are listed as they appeared in the literature. If you cannot find the chemical you are researching please double-check alternative names for the chemical, e.g. 2,5-dimethayl-4-hydroxy-3(2H)-furanone is listed in this table as furaneol.

Chemical	Sensory Descriptor	Taste Threshold Concentration (µg/L)	Odor Threshold Concentration (µg/L)	Temperature of Test °C	Reference
2-methylisoborneol			0.004-0.009	15-35	Ito et al. 1988
2-methylisoborneol	slight earthy		0.005 - 0.010	25	Krasner et al. 1985
2-methylisoborneol	musty, earthy		0.006 - 0.010	45	Rashash et al. 1997
2-methylisoborneol	musty		0.004-0.012	25	Sano 1988
2-methyl-isoborneol		0.0025-0.018		25	Young et al. 1996
2-methyl-isoborneol			0.0063-0.015	40	Young et al. 1996
geosmin			0.022-0.180	15-35	Ito et al. 1988
geosmin	earthy, corn, musty		0.006 - 0.010	45	Rashash et al. 1997
geosmin	musty		0.094-0.360	25	Sano 1988
geosmin		0.0075-00.016		25	Young et al. 1996
geosmin			0.0013-0.0038	40	Young et al. 1996

Figure 5 | Taste and odor threshold concentrations summarized from literature reports and included in the decision tree CD ROM.

CONCLUSIONS

The decision tree and the protocol for solving taste and odor problems presented in this paper have clearly illustrated that:

- Control of tastes and odors is critical to the success of a water utility.
- The decision tree is a strategic arrangement of questions and solutions to taste and odor problems.
- Communication with stakeholders is essential at many stages of assessing and solving an aesthetic problem to gain stakeholder trust and understanding of the problem.
- Knowing the source and characteristic of a taste and odor problem is critical to solving off-flavor problems.
- Using the decision tree can clarify the problem and yield information to help control troublesome taste and odor events.

ACKNOWLEDGMENTS

The authors are grateful to the many professionals that participated in the expert workshop and the beta test of the decision tree. The authors also wish to thank the AwwaRF project advisory committee (Andrea Dietrich, Wendy Nero and Naomi Roseth) for their guidance. This project was funded under an AwwaRF research grant, project no. 2777, Albert Ilges, Project Manager.

This paper was possible through funding from the Awwa Research Foundation. The information contained herein is based upon Intellectual Property that is jointly owned by McGuire Environmental Consultants, Inc. and the Foundation. The Foundation retains its right to publish or produce the Jointly Owned Intellectual Property in part or in its entirety.

REFERENCES

Izaguirre, G., Hwang, C. J., Krasner, S. W. & McGuire, M. J. 1982 Geosmin and 2-methylisoborneol from cyanobacteria in three water supply systems. *Appl. Environ. Microbiol.* **43**(3), 708–714.

Krasner, S. W., Hwang, C. J. & McGuire, M. J. 1983 A standard method for quantification of earthy-musty odorants in water, sediments and algal cultures. *Wat. Sci. Technol.* **15**(6/7), 127–138.

Krasner, S. W., McGuire, M. J. & Ferguson, V. B. 1985 Tastes and odors: the flavor profile method. *J. AWWA* **77**(3), 34–39.

Mallevialle, J. & Suffet, I. H. 1987 *Identification and Treatment of Tastes and Odors in Drinking Water*. AwwaRF and AWWA, Denver, CO.

McGuire, M. J. 1995 Off-flavor as the consumer's measure of drinking water safety. *Wat. Sci. Technol.* **31**(11), 1–8.

McGuire, M. J. & Gaston, J. M. 1988 Overview of technology for controlling off-flavors in drinking water. *Wat. Sci. Technol.* **20**(8/9), 215–228.

McGuire, M. J., Graziano, N., Sullivan, L., Hund, R. & Burlingame, G. 2004 *Water Utility Self Assessment for Management of Aesthetic Issues*. AwwaRF and AWWA, Denver, CO.

McGuire, M. J., Krasner, S. W., Hwang, C. J. & Izaguirre, G. 1983 An early warning system for detecting earthy-musty odors in reservoirs. *Wat. Sci. Technol.* **15**(6/7), 267–277.

First received 15 December 2004; accepted in revised form 7 May 2005