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The EU Drinking Water Directive: The Boron Standard and Scientific Uncertainty

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ABSTRACT

In 1998 the European Union (EU) revised its Drinking Water Directive, which is responsible for regulating the quality of water in the EU intended for human consumption. Specifically, the EU added a new standard for the element boron in drinking water (1 mg/l). Yet, because of scientific uncertainty concerning the causes and magnitude of the boron problem in Europe during the regulatory standard-setting process, we find that full compliance with the new drinking water standard for boron has been hampered. Prior to the standard's enactment, it was unclear whether boron was derived from natural or anthropogenic sources. A new geochemical study reveals that a significant part of the boron contamination is derived from natural sources. Countries such as Italy and Cyprus with high natural boron concentrations in their drinking water are, thus, finding that compliance with the new EU boron regulation is more difficult and expensive than originally anticipated. Copyright © 2005 John Wiley & Sons, Ltd and ERP Environment.

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Introduction

Over the last few years, the European Union (EU) has introduced and revised several pieces of water legislation, which have generated a new set of challenges for its member states to achieve national compliance. Most recently, in 2000 the EU passed the Water Framework Directive – an overarching piece of legislation that brings together all existing EU legislation on water resources (Article 4). In 1998 the EU had revised its Drinking Water Directive (DWD)

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(98/93/EC), which is responsible for regulating the quality of water that is intended for human consumption. The DWD requires that the EU member states comply with a number of water quality standards and health parameters, and in the 1998 DWD revisions the EU added several new chemical parameters – one of which is a 1 mg/l parametric value for the element boron in drinking water (OJ L330/32). The boron directive largely affects the European member states in the Mediterranean basin (e.g. Cyprus, Greece, Italy, and Spain), as some of their groundwater bodies contain exceptionally high levels of boron (Kloppmann *et al.*, 2003; Vengosh *et al.*, 2004).

Full compliance with the new boron standard, however, has been hampered by scientific uncertainty concerning the causes and magnitude of the boron problem in Europe during the EU regulatory standard-setting process. Through the lens of the boron standard, we disaggregate the general problem of scientific uncertainty in the regulatory standard-setting process into two components – health effect and cause of the problem – in order to understand better national compliance. A good deal of attention has focused on the precautionary approach as a mechanism to contend with scientific uncertainty concerning the health effects of a potential pollutant in the EU policy-making process. Instead, we shift attention to the way in which scientific uncertainty about the causes of a pollutant can impede compliance with new regulatory standards.

The new boron standard, in particular, illuminates how policy-making based on inconclusive scientific evidence concerning the causes of a pollutant can create subsequent compliance problems for EU member states in developing timely and economically viable management solutions. The rest of the article proceeds as follows. First, we discuss conventional explanations for the failure of states to comply with EU directives. Our argument concerning the impact of the two components of scientific uncertainty (i.e. health effects and cause of the problem) during the regulatory standard-setting process then ensues. Second, we provide a brief overview of the element boron. Third, we describe the level of scientific uncertainty that existed in the EU prior to the boron standard concerning the sources of the boron problem. Fourth, we focus on the implementation of the boron standard in Italy and Cyprus to demonstrate our argument. Last, we offer concrete policy proposals for overcoming the problem of scientific uncertainty in the regulatory standard-setting process.

National Compliance and Scientific Uncertainty

Recent research on European environmental policy has focused both on the policy process that has resulted in the different directives (see, e.g., Page and Kaika, 2003; Kaika and Page, 2003; Kaika, 2003; Richardson, 1994) and national compliance with these directives (see, e.g., Börzel, 2000; Jordan, 1999; Weale *et al.*, 2000; Ward *et al.*, 1997). In this article, we apply the widely accepted definition of compliance, which includes both the transposition of international law (or in this case EU law) into domestic law and the achievement of practical results (Weiss and Jacobson, 1998).

A common theme that underlies these studies on national compliance is that the EU member states have failed to transpose EU environmental policy in general and water policy specifically into national law and to achieve practical results. Many explanations for the EU's long history of compliance problems emphasize national norms, institutional fragmentation and what have been described as 'other national peculiarities' (Weale *et al.*, 2000). Börzel (2000), for example, finds that a misfit between a state's administrative and legal structures and EU policy can contribute to a state's inability to comply with EU environmental policy. La Spina and Sciortino (1993) argue that the specific national and cultural characteristics of the Mediterranean countries (also known as the 'Mediterranean syndrome') have hindered their compliance with EU environmental legislation. Still others suggest that compliance problems arise because of a lack of consideration for ground-level implementation when the directives were drafted that includes 'variations in the technical, managerial and institutional capacity of member states' (Ward *et al.*, 1997, p. 207).

While the lack of suitability of EU standards to local conditions and the neglect of ground-level implementation undoubtedly create compliance problems, we argue that to understand better compliance problems attention must also focus on the uncertainty surrounding the cause of the problem in the regulatory standard-setting process. The above-mentioned studies fail to link explicitly the different components of scientific uncertainty during the regulatory standard-setting process to national compliance. We, thus, offer an alternative explanation for poor compliance that posits that scientific uncertainty surrounding the definition of potential causes during the policy-making cycle sets in motion many of the compliance problems alluded to in the literature on EU environmental compliance. Yet, unlike Jordan (1999), for example, who argues that one of the main reasons for the poor implementation of European water policy is its lack of a sound scientific foundation regarding the health effects, we argue that the lack of scientific evidence regarding the causes of the problem is under-addressed.

During the first stage of the policy-making cycle in which an environmental problem is defined and placed upon the policy agenda, the role of scientific uncertainty regarding potential health effects is most prominent. If scientists cannot agree upon the effects of a certain environmental pollutant for human health or the natural environment, it is often difficult to get policy-makers to pay attention to the issue. In response to the problem of scientific uncertainty during the problem-definition stage, the EU has promoted the precautionary principle and relied upon scientific evidence from leading scientists to devise its environmental policies. The precautionary principle obliges states to take action even before it is fully known what are the real effects of an environmental problem so as to prevent potential harm to the population (see, e.g., O'Riordan and Cameron, 1994). The 2000 EU Communication on the Precautionary Principle signaled the EU's commitment to the precautionary principle as a risk management strategy to prevent 'potentially dangerous effects on the environment, human, animal or plant health' in the absence of sound scientific evidence that could prove otherwise (European Commission, 2000). As a result, over the last decade the precautionary principle has guided EU environmental policy-making. It has also become one of the core components of EU water policy (see, e.g., *Handbook on the Implementation of EC Environmental Legislation*). When faced with inconclusive proof of significant harm to the population, the EU is, thus, obligated to act and strengthen its policies (DG Environment and Project Management Group, 2003).

In the water sphere, the EU must ensure 'good status' drinking water for its population. As a result, the EU has turned to select communities of scientists to help it enact new standards that limit harmful pollutants in drinking water. According to Richardson (1994), scientists from the World Health Organization (WHO), for example, define the water policy agenda because they possess most of the knowledge and hence power to declare whether a certain pollutant is potentially harmful.

While the precautionary principle has become a useful policy tool to assist the EU in overcoming scientific uncertainty during the problem-definition stage and bring about new environmental standards, it does not adequately deal with the uncertainties as to the cause of the problem. As a result, national compliance is unachievable for reasons related to the lack of scientific evidence in the policy-making cycle regarding the cause of the problem. First, the absence of any cost/risk analyses results in a demand for standards that are often impossible to achieve (Jordan, 1999). Second, scientific uncertainty regarding the cause and magnitude of the environmental problem renders conventional solutions inappropriate and thus impedes national compliance. In short, while the precautionary principle has enabled the EU to enact new standards even when inconclusive evidence exists about the risk to human health, the lack of clear scientific evidence about the causes of the source of a pollutant turns out to be the main barrier to achieving national compliance. Thus, the absence of scientific clarity surrounding the specific causes of a pollutant makes it difficult to ensure that effective action can be taken once EU legislation is transposed into national law. Furthermore, in instances where both the causes and effects of the problem remain inconclusive, those responsible for implementation (e.g. national and local water authorities and managers) are left with the burden of proof to demonstrate that the potential health risk might not be as harmful as assumed and hence that the EU standards are too strict. Moreover, they must also investigate the origins of the problem so that they can develop appropriate solutions.

The Element Boron

Boron is an inorganic element that is dissolved in water. Typically, low-saline ground water and rivers contain low concentrations (<0.1 mg/l, Neal *et al.*, 1988; Wyness *et al.*, 2003) whereas saline water may show high concentrations up to several tens of mg/l (4.7 mg/l for seawater). The potential sources of boron contamination in water resources are either anthropogenic (pollution from sewage effluents, boron enriched fertilizers and land-fill leachates) or natural (e.g. water–rock interaction, sea water encroachment, mixing with fossil brines or hydrothermal fluids) (Vengosh *et al.*, 1994, 1999).

Boron has various industrial uses, ranging from the glass and ceramic industries to detergents and soaps. The industrial applications of boron result in the accumulation of boron in industrial wastes that then permeate into the natural environment. The main industrial use of boron that affects the environment is the detergent industry (Waggott, 1969; Raymond and Butterwick, 1992; Vengosh *et al.*, 1994). Because sodium perborate is an excellent bleaching agent, detergent companies have added it to their washing powders for decades. Consequently, the high content of boron in detergents results in the accumulation of boron in domestic wastewater, particularly in industrial countries. Typically, the boron content in domestic wastewater ranges from 0.5 to 1 mg/l. Surveys of boron concentration in rivers in the United Kingdom (Neal *et al.*, 1998) and other EU states (Wyness *et al.*, 2003) show that in most cases the boron concentration in rivers does not surpass the drinking water value of 1 mg/l. Furthermore, high levels of boron concentrations were found mostly in rivers that are associated with urban and industrial drainage relative to those from rural areas (Neal and Robson, 2000), thus indicating a direct link between boron contamination in rivers and sewage pollution.

Since a large fraction of the rivers in Europe are polluted, over the last few decades many European countries have instead turned to ground water as their main source of drinking water. At high levels (i.e. above 1 mg/l), boron is considered a serious threat to the use of ground water for both drinking and agricultural purposes. Boron, for example, affects plant growth and yields because it is biologically an essential micronutrient for many plants; an overdose or an underdose of boron can result in toxicity or deficiency symptoms in plants, respectively. In fact, a level of boron in irrigation water exceeding 1 mg/l can significantly affect the yield of sensitive crops such as citrus fruits. In contrast, borate minerals are added to fertilizers to compensate for boron deficiencies in areas where the natural soil lacks boron (e.g., Western Central Valley, California).

Prior to the introduction of the EU boron standard, few studies existed that examined the direct effects of boron – especially from ground water – on human health.[1] Rather, the 1993 WHO guidelines for drinking-water quality proposed a 0.3 mg/l (later revised to 0.5 mg/l) standard for boron in drinking water largely based upon a 2-year study on dogs that was published in 1972 (WHO, 1998). Such toxicological studies that focused on high concentration oral exposure of laboratory animals showed that boron toxicity could lead to reduced fertility and sterility (see also, e.g., Mastromatteo and Sullivan, 1994). The only proven effects of acute exposure on humans (e.g. workers in borax mining and production facilities) were short-term irritation of the upper respiratory tract (Garabrant *et al.*, 1984, 1985; Wegman

[1] For a comprehensive survey of research on boron, see WHO, 1998.

et al., 1994). Since then, two studies that examined fertility and secondary sex ratios in response to long-term exposure to boron among the population in two geographical regions in Turkey have found no negative effects on fertility (Sayli *et al*., 1998, 2001). An influence of boron intake on certain human key enzymes, however, cannot be excluded (Huel *et al*., 2004).

Scientific Uncertainty and The Sources of Boron Contamination

Based upon the above-mentioned toxicological studies combined with input from different stakeholders (e.g. water supply companies), the EU adopted a standard of 1 mg/l for drinking water (interview with CIGRI, Tuscany, Italy, 2001). Prior to the new boron standard, the EU had only listed boron as a recommendation (1 mg/l), which countries could exceed if they so wished. In fact, the United Kingdom had a standard of 2 mg/l, and Italy only had a guideline of 2 mg/l. While this new standard is more tolerant than the revised WHO recommendation (0.5 mg/l), it still is stricter than many EU member states' previous standards and guidelines. Moreover, this new boron standard is a precautionary measure since the current classification of boron as a pollutant in the new DWD has rendered large amounts of ground water unusable for human consumption in many of the Mediterranean basin countries because of boron's suspected health effects (Kloppmann *et al*., 2003). The new standard has required the EU member states to take action, especially regarding their ground water resources.

In addition to the inconclusive evidence to the risks for human health, uncertainty concerning the causes of the boron problem in Mediterranean water resources also existed during the regulatory standard-setting process. At that time, it was unclear whether boron was a natural contaminant or an anthropogenic one, and, depending upon the source of the boron pollution, different management solutions are possible for ensuring compliance.

When the EU considered the WHO boron standard, representatives from the detergent industry (Roberts, 1995) claimed it was uncertain whether the source of the boron in the ground water was derived from human pollution generated from the addition of boron to detergents, which then results in the formation of boron-rich sewage. Similar to other inorganic ions, boron is not removed during standard sewage treatment processes. As a consequence, even treated wastewater typically has high boron concentrations. Available data from surveys of boron concentrations in European rivers that indicated that boron in rivers was directly linked to domestic sewage and/or industrial pollution (Neal *et al*., 1998) supported the perception that boron in ground water was also from anthropogenic sources. The most obvious management solution then is to reduce the amount of boron in detergents since they are the principal source of boron in sewage effluents. Compliance, as a result, would turn out to be feasible in the short term. In fact, some countries (e.g. Cyprus) had already taken such measures to reduce the boron level in detergents and consequently in domestic sewage effluents.

Yet, at the time the boron standard was promulgated, it was unclear what the source of the boron in the drinking water was because a comprehensive survey of boron-rich waters in Europe – especially concerning ground water resources – had not been carried out. Because of this lack of scientific evidence about the source of the boron-rich ground water, some water suppliers contested the new standard, arguing that it would be difficult to enforce in areas of high boron in the ground water, especially if it turned out that the source was natural (interview with CIGRI, Italy, 2001).

If the source of the boron is 'geogenic' and derived from natural reactions with the rock of the host aquifers, management solutions that ban the use of borates in detergents are largely ineffective. Moreover, it is not possible simply to restrict the use of ground water resources in countries where ground water is the primary source of drinking water. Although the new standard requires the water authorities to regulate the amount of boron in drinking water, the removal of natural boron, it turns out, demands technological solutions that are often potentially costly and mostly still at an early stage of development. Dilution of boron-contaminated water with low boron water, for example, can be costly, especially when low boron water has to be transported over long distances.

Thus, in order to address the extensive uncertainty concerning the definition of the potential causes of the boron contamination, research carried out after the enactment of the new boron standard by the EU Fifth Framework Program – BOREMED ('Boron contamination of water resources in the Mediterranean region: distribution, sources, social impact and remediation') – has mapped the boron problem in the Mediterranean states and delineated the source of the boron contamination (see http://boremed.brgm.fr, accessed 28 August 2004). In addition, the project examined the institutional water framework in different countries with high boron levels in order to evaluate the effect of the institutional setting on national compliance with the EU DWD. Data collected from national and regional databases for more than 6000 selected ground water points as part of the BOREMED project reveal that around 10% of the investigated water resources in the Mediterranean basin have boron levels exceeding the new EU DWD (Kloppmann *et al.*, 2003). Results show that large volumes of ground water in Cyprus (up to 13 mg/l), the Chalkidiki peninsula in Greece (6 mg/l) and the Cornia River basin in Tuscany, Italy (8 mg/l), are currently unusable due to high boron. In Tuscany, Italy, more than 30 percent of the local ground water has boron content exceeding the parametric value of the DWD of the EU of 1 mg/l. In addition, high boron in ground water from the Lower Andarax basin in southeastern Spain was reported with boron concentrations up to 10 mg/l (Sanchez-Martos and Pulido-Bosch, 1999). Outside the EU, boron in drinking water is a problem in the southern part of the Mediterranean coastal aquifer that is shared between Israel and the Gaza Strip; here, boron concentration in the ground water reaches 3 mg/l (Vengosh *et al.*, 2002b). High boron in ground water is also found in western Turkey (Cöl and Cöl, 2003; Vengosh *et al.*, 2002a). In Kutahya Province in Turkey the average boron content in 382 water samples (tap water and natural springs) is 10 ± 4 mg/l (Cöl and Cöl, 2003). In short, according to the new drinking water standard, many ground water bodies along the Mediterranean cannot be used to supply drinking water.

National Compliance in Cyprus and Italy

In order to understand how scientific uncertainty surrounding the definition of the potential causes has an impact on national compliance, we focus on Cyprus and Italy for several reasons.[2] First, in both these cases, boron contamination in drinking water is severe, and the source of the boron contamination turns out to be a largely natural phenomenon. Second, these countries differ in the scale of the problem. In Italy the boron problem is a local problem rather than a national one, and as a result, the local water companies in conjunction with the regional water authority are responsible for compliance. In Cyprus, the boron problem is a national problem. Third, Cyprus enabled us to examine the effects of the EU accession process on the way in which Cyprus addressed its boron problem.

Cyprus

Water is a scarce resource in Cyprus, which is the third largest island in the Mediterranean. All the aquifers in Cyprus are exploited beyond their safe yield (i.e., pumping exceeds replenishment), resulting in a water deficit of about 40 MCM per year (Socratous, 2000). One of the main water quality

[2] Besides on-site field investigations in Italy and in Cyprus, interviews were carried out in Italy with representatives from ATO 5, the Tuscany Regional Water Department and the water supply companies. In Cyprus, interviews were conducted with the Water Development Department.

problems in Cyprus is water salinization owing to a combination of seawater intrusion (Socratous, 2000), natural saline waters and anthropogenic sources such as agricultural return flows enriched in nitrates, pesticides and insecticide residuals from agricultural activities.

In May 2004 Cyprus joined the EU, and as part of its accession negotiations Cyprus adopted new legislation in order to ensure full implementation of the DWD. By May 2001, Cyprus had transposed all the provisions (i.e. water quality parameters) in the DWD into national law (http://europa.eu.int/scadplus/leg/en/lvb/e15111.htm, accessed 29 August 2004). Moreover, the Cypriot government promulgated a new Water Entity Law (2001) so that its legislation is in agreement with the Water Framework Directive (see, e.g., Getimis and Markantonis, 2003). To date, the Water Development Department is responsible for carrying out the water policy of the Ministry of Agriculture, Natural Resources and Environment. However, because of the need to harmonize water management policies with the Water Framework Directive, Cyprus has begun to reform its whole structure of water management through the creation of these new water entities (i.e. 2001 Water Entity Law). These water entities will be solely responsible for formulating and implementing water management policies.

Cyprus is one of the few European governments with a long history of policy action to deal with boron because of an early awareness that boron is toxic for certain agricultural crops. Since 1974, Cyprus has taken measures to restrict the use of boron compounds in any application that might give rise to high boron containing effluents that could pollute surface and ground water. In particular, Cyprus restricts the amount of boron in its detergents in order to reduce boron contamination in treated wastewater, which is then used for irrigation. While the reduction in boron in treated sewage may prove to be beneficial for agriculture since there will be less boron contamination in the irrigation water, these regulations will have negligible effects for improving the quality of ground water used for drinking purposes.

Prior to the new EU boron standard, however, boron was not considered a drinking water problem since the water authorities had only recorded a small number of villages with high levels of boron in their drinking water (interview, Water Development Department, 2002). Once it became known that the boron contamination in Cyprus was more widespread than originally assumed and was derived from natural sources, it became apparent that previous approaches that include the reduction of boron in detergents were not sufficient for Cyprus to meet its obligation to abide by the EU standard for drinking water. Moreover, the simple solution of diluting boron-rich water with boron-poor water is not applicable because of water scarcity and the lack of suitable boron-poor water. Since the source of the boron contamination in Cyprus is primarily natural, Cyprus has been forced to turn to more costly approaches to provide 'good status' water that is in compliance with the boron standard for drinking water. In particular, Cyprus has turned to desalinated seawater to increase supply to meet its rising demand for drinking water. Reverse osmosis desalination has tremendous potential as a supplier of new water for the 21st century, especially in areas of the world where water is scarce or the quality is inadequate. Yet, its widespread application is hampered by the fact that standard reverse osmosis desalination only partially removes boron.

In sum, the lack of understanding that boron was naturally occurring rather than anthropogenic during the regulatory standard-setting process has created a compliance dilemma for Cyprus in its endeavors to implement the EU DWD. On the one hand, Cyprus has revised its institutional and legal structure to ensure harmonization with the EU directives; yet, on the other, the boron standard still remains unachievable precisely because past solutions that would restrict the amount of boron added to detergents are inadequate for full compliance. Rather, uncertainty concerning the potential causes of boron contamination in the policy-making cycle has forced Cyprus to invest in technological innovation (e.g. reverse osmosis or boron-specific resins) to supply drinking water that meets the new boron standard from both ground water and desalinated water.

Italy

Unlike Cyprus, where the boron problem is national in scope, in Italy it is more localized in areas with geothermal activity such as in the Cornia River basin in southern Tuscany. The water resources from the alluvial aquifers of the Cornia River basin have been intensively exploited since the 1920s for regional water supply. At present, more than 1000 wells exploit about 40×10^6 m^3/year of ground water from the main hydrologic units of the Cornia alluvial aquifer. The significant increase in water exploitation over the last century (about 70%) and the parallel decrease in local precipitation are responsible for the draw-down of the water table that has led to deteriorating water quality, particularly seawater intrusion in the coastal part of the aquifer (Pennisi *et al.*, 2004; Bianchini *et al.*, forthcoming 2005).

In addition to ground water salinization, boron contamination occurs in both the coastal and inland parts of the Cornia basin. The boron concentrations in ground water that are used for drinking water range from 1 to 4 mg/l and can locally reach 8 mg/l (D'Avino and Spandre, 1995; Pennisi *et al.*, 2004; Bianchini *et al.*, forthcoming 2005) and thus clearly exceed the EU limit of 1 mg/l. Geochemical and isotopic data generated by the BOREMED project reveal that the boron contamination in the Cornia River basin is also a natural process (Pennisi *et al.*, 2004).

Prior to the new EU standard, boron was never considered a problem for drinking water or agriculture in the Cornia River basin; rather, the high level of salinity in the water was seen as much more pressing, especially for the agricultural sector (interview with ATO5, Tuscany, 2003). In fact, before the introduction of the boron standard, Italy only had a guideline for boron in drinking water of 2 mg/l. According to interviews (2003) with the local water company and regional water authority, they never paid particular attention to the high levels of boron largely because they did not see any immediate health risks and the local population never complained about the taste of the drinking water.

As a result, the regional water authority has only addressed the boron problem as part of the larger program of restructuring the water sector in Tuscany, Italy, to meet its EU obligations. In order to comply with the Water Framework Directive, Italy had to reform its system of water management so that water users will pay the real price for drinking water at the same time that its water management institutions must ensure good quality drinking water. Italy has 21 regions, 100 provinces, and about 8000 municipalities (Water Services, the Tuscan Model, 2003). Until the 1990s water service management in Italy (i.e. water supply, sewerage and purification) was entrusted to the municipalities that supplied domestic water either through public service bodies or through licensing concessions to private companies. Owing to the high fragmentation of the municipalities, hundreds of water boards existed, which resulted in poorly managed and often under-budgeted water supply systems (Water Services, the Tuscan Model, 2003).

In response to both the deteriorating system of water management at the domestic level and demands from the EU for harmonization, the Italian government has authorized the creation of new water basin authorities. As part of Italy's transposition of the Water Framework Directive into Italian national law that requires water to be managed on the basis of river basins, rather than according to geographical or political boundaries (interview with ATO 5, Italy, 2003), these new water basin authorities also have the responsibility for ensuring compliance with the drinking water standards (see also Rinaldi and Salvati, 2002). Tuscany with its 287 municipalities was divided into six optimal territorial areas (ATOs). In each ATO all the organizational and service functions previously held by the municipalities have been franchised to a single water company. Most of the boron contamination of drinking water is located in ATO 5, which covers the Cornia River basin. At present, with the creation of ATO5, ASA Spa (*Azienda Servizi Ambientali*) is responsible for ensuring that the drinking water does not contain boron above 1 mg/l. It received the franchise for the provision of drinking water after merging with several other water companies such as CIGRI, which previously was responsible for the supply of the drinking water in the Cornia River basin.

In contrast to Cyprus, where compliance depends upon action at the national level, in the Cornia basin compliance is very much a local issue. Here, the uncertainty concerning the definition of the causes during the policy-making cycle has made compliance even more difficult for the local water suppliers. They must bear the costs of compliance that entails devising new management solutions to reduce the level of boron in the drinking water. Moreover, because boron is a local issue, the role of scientific uncertainty concerning the direct health effects on the population is also more pronounced. The local water company argues that compliance is especially costly given that the risks to human health are still not sufficiently substantiated. Rather, if boron is damaging to human health, they should have been aware of it before the new standard was passed given that the local population has for generations been drinking water in which the boron content has reached 4 mg/l (interview with ASA Spa, Italy, 2003). Thus, compliance in Tuscany has been constrained by the dual role of scientific uncertainty in the regulatory standard-setting process – that is, concerning the direct effects on human health and the causes of the boron contamination.

Water managers in the Cornia River basin have turned to water planning measures that emphasize the dilution of boron-contaminated water as a temporary solution given the local nature of the boron problem. At present, the local water supply company mixes the boron-rich water with high quality water to reduce the level of boron in the water that is supplied for both drinking and agricultural purposes. The longevity of this solution is limited primarily because of the diminishing amounts of available high-quality water. An alternative treatment is reverse osmosis or boron-specific removal, but the higher costs would be transferred onto the consumer. Prior to the new administrative reforms that have created the ATOs, most Italians have not paid the real cost for their drinking water supplies so it remains unclear the extent to which residents in the Cornia Valley would be willing to pay for more expensive water that meets the EU boron standard for drinking water.

In sum, because the source of the boron is natural and not anthropogenic, for the water authorities in the Cornia River basin to ensure compliance with the new EU standard, they must turn to innovative management solutions, which include finding alternative sources of drinking water.

Implications and Recommendations for Improving National Compliance

Overall, the uncertainty concerning the sources of the boron contamination that existed during the EU regulatory standard-setting process has created a compliance dilemma for countries with boron-rich water. While it turns out that scientific uncertainty regarding the health effects of boron in drinking water facilitated the enactment of the new boron standard, the scientific uncertainty about the causes of the boron in the drinking water has hampered national compliance. On the one hand, the respective water authorities have undertaken concrete efforts to ensure compliance such as embarking upon institutional reform and transposing the new standard into national law. They have also proven their willingness to pay higher costs to comply with the new standard. Yet on the other hand, full national compliance has proven difficult precisely because of the lack of conclusive data about the source of the problem when the standard was enacted. Thus, while one could argue that compliance would have been cheaper and easier if the boron contamination had been anthropogenic since the costs would have fallen on the detergent companies, this overlooks the concrete steps taken by the national and local water authorities in Cyprus and Italy to ensure compliance once it was discovered that the source was natural.

Jordan (1999, pp. 13–14) claims that EU water policy has proven 'to be one of the most expensive and . . . one of the toughest to implement' and 'increasingly unpopular with member states, who believe key standards are unnecessarily stringent'. Yet, few have suggested ways in which to prevent such compliance dilemmas from arising prior to the promulgation of new drinking water standards. Here, we suggest some steps that can be taken in regards to the boron case.

First, in order to improve national compliance and subsequently reduce uncertainty about the appropriate management solutions, the EU should invest in reducing the level of uncertainty concerning the causes of a pollutant even while pursuing policies based upon the precautionary principle. Without adequate information about the causes of the pollutant in the regulatory standard-setting process, the responsible bodies for compliance must then invest in studies to delineate the cause of the problem, which can delay the implementation of appropriate solutions. In the case of the boron standard, the finding that the boron was derived from natural sources has forced affected countries to invest in costly 'reparative' technologies rather than just reducing the level of sewage waste if the source had been anthropogenic boron.

Second, even if the EU cannot wait for conclusive scientific evidence about the potential health effects of a contaminant, it should build into its policy-making process a time frame for carrying out scientific studies to determine whether the presumed health risk does, indeed, exist. This would also create an efficient mechanism for updating new information about the costs and benefits of new environmental standards, since the EU has rarely moderated its standards (see, e.g., Jordan, 1999). This is particularly important for countries such as Italy in which the boron problem is local. Without a clear understanding of the source of the contamination, EU regulatory standards can lock countries into having to rely upon expensive technological solutions before clear scientific data is available to either prove that boron is negative for human health or not.

If conclusive evidence had existed during the EU policy-making process that much of the boron found in groundwater was natural, health impact studies could have then been carried out concurrently in regions where the population has been exposed to boron in the drinking water for decades (see, e.g., Sayli *et al.*, 1998, 2001). In fact, recent epidemiological studies carried out in Northern France where the boron was determined to be natural do not substantiate the idea of a deleterious effect of boron on human health at low-dose exposures (up to 1 mg/l) (Yazbeck *et al.*, submitted). In short, reducing uncertainty about the source of the contaminant can also have positive effects on reducing the uncertainty regarding the health effects and enable better cost/risk analysis for developing feasible management solutions.

Third, to facilitate national compliance, the EU should support close consultations with local and national stakeholders (i.e. water supply companies and basin authorities) even during the earliest phases of the regulatory standard-setting process. Institutional channels should be strengthened so that EU regulatory bodies can, thus, take into account new information about the causes of the contamination and its effect on national compliance. In the case of boron, national compliance is, moreover, contingent upon the local and national water authorities having reliable information concerning the source and magnitude of the boron contamination. Finally, mitigating the uncertainty surrounding both the sources and effects of the boron problem may also reduce opposition from water supply companies and consumers to comply with such new directives.

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