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Scientific Commentary

Better environmental regulation - contributions from risk-based decision-making

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Abstract

Internationally, pressure is being put on governments and regulators to develop more modern forms of regulation that deliver more for less and in better ways. This review considers the ways in which one large regulator, the Environment Agency for England and Wales, has responded to such pressure by developing and implementing risk-based approaches to regulation. After exploring the context for and key elements of risk-based environmental regulation, we consider the evolving influence of such approaches. We discuss the impacts of risk-based approaches against the UK Government's principles for better regulation and against the key criteria for policy evaluation before considering some of the key challenges that still need to be addressed in this area of regulatory activity. These relate to the need to i)

understand best practice and promote consistency in risk based regulation; ii) develop reliable, responsive forms of risk assessment and monitoring; iii) build capacities for responsive risk regulation; iv) evaluate the influence of different regulatory styles; and v) better understand the potential role of the private sector.

Keywords: risk, modern, better, regulation, policy, Environment Agency.

1. Introduction

Driven by concerns about public sector expenditure and private sector competitiveness, many commentators have long been critical of the role that regulation plays in modern economies. Gunningham and Grobasky (1999) encapsulate these criticisms suggesting that regulations 'are not effective in delivering their purported goals; or efficient in doing so at least cost; nor do they perform well in terms of other criteria such as equity, administrative viability or political acceptability'. Regulation has therefore been seen to perform badly when measured against all of the key criteria for policy evaluation. However, command and control regulation remains an important policy instrument, and broader forms of regulation are emerging, centred, for example, around market-based or information-based instruments. As a consequence, pressure is being put on governments and regulators to develop better (or more modern) forms of regulation that deliver more for less and in better ways. Risk-based, or more correctly, risk-informed regulation is one contributor to this debate (e.g. Rothstein et al., 2006).

Internationally, there has been considerable emphasise placed on the need to develop better regulation in recent years. The OECD for example first issued its influential recommendations for regulatory reform in 1997; these subsequently evolved into the OECD Guiding Principles for Regulatory Quality and Performance in 2005 (OECD, 2005). At a

European level, the EU initiated a drive towards better regulation in 2002, and has published three strategic reviews of better regulation in the EU since 2006 (c.f. European Commission, 2009). The UK has been an active participant in these international and European debates and domestically the UK government's Better Regulation Task Force has been an influential voice within government since its creation in 1997[1]. It has called for regulators to adhere to its principles of better regulation by ensuring that regulations are targeted, proportionate, consistent, transparent and accountable.

As a regulator that employs *ca.* 12,000 people and has an annual budget of over £1 billion, the Environment Agency has been developing its response to the better regulation agenda for some years. It has done this most notably through the adoption of risk based approaches to regulation in its broadest sense, that seek to focus scarce regulatory resources on the highest risks and the worst performers, thereby, it is hoped, securing sustainable environmental outcomes, delivering public sector efficiency gains and reducing business burdens.

After examining recent experiences with risk-based regulation in the Environment Agency, this commentary highlights some key gaps in the knowledge base and some of the future challenges in the field. We conclude by considering the extent to which risk-based approaches have enabled, or could in the near future allow the Environment Agency to continue to improve the implementation of the principles of better regulation and the performance (i.e. the efficacy, efficiency, equitability, administrative viability and political acceptability) of environmental regulation.

2. Risk based environmental regulation

[1]Its growing influence is reflected in the adoption of the Legislative and Regulatory Reform Act of 2006 and creation of the Department for Business, Enterprise and Regulatory Reform in 2007.

Reflecting the broader international agenda on better regulation, risk-based environmental regulation has been explicitly promoted in the UK for over ten years (Parliamentary Office of Science and Technology, 1996; Halfacree, 1998). As well as being driven by the better regulation debate above, it arose through an increased emphasis on better risk governance in Government departments (Interdepartmental Liaison Group on Risk Assessment, 1998; OXERA, 2000; Hampton, 2005; Strategy Unit, 2002) and agencies following events such as the BSE (House of Commons, 2000) and foot and mouth crises, and the associated concerns about poor public trust in Government decisions on risk (House of Lords, 2000; ESRC Global Environmental Change Programme, 2000; Green Alliance, 2000; House of Lords, 2006). Given that it has evolved rapidly since its adoption, it is our view that there is sufficient operational experience among regulators (Her Majesty's Inspectorate of Pollution, 1995; Environment Agency, 1997; European Commission, 1998; Department of Environment, Transport and the Regions, 1999; Department of Environment, Transport and the Regions, 2000) to reflect on the contributions that risk-based environmental decision making (Department of the Environment, 1995; DETR and the Environment Agency, 2000) can make towards modern or better environmental regulation.

The Environment Agency has wide-ranging regulatory responsibilities for flood risk management and environmental protection. It adopts environmental risk assessment to inform its decisions at both the strategic and operational levels. Strategically, the Agency leads Government on the application of environmental risk assessment, with the government Department for Environment, Food and Rural Affairs (Defra) setting the policy context and direction (Defra, 2000). At the operational level, the Environment Agency requires environmental risk assessments to inform its decision making and, by virtue of its generalised powers, may request a risk assessment of any operation it considers may have a detrimental impact on human health and the environment. Guidance on environmental risk assessment

and management is in place and implemented (Pollard, 2001; Pollard, 2002); several Agency-administered regimes are noted as being risk-based (*e.g.,* contaminated land, waste management, flood risk management, process industry regulation, river basin management); and risk-informed regulatory processes are in place for targeting proportionate regulation, securing efficiency gains and informing workforce (resource) planning.

Many of the risk-informed regulatory processes are based on the application of what is known as 'operator and pollution risk appraisal' (OPRA) (Her Majesty's Inspectorate of Pollution, 1995; Environment Agency, 1997; Environment Agency, 1997). OPRA seeks to assign a ranking to regulated sites according to their innate hazard and the capacity of the operator to manage the likelihood of these hazards being realised – the operator's demonstrable performance in risk management. OPRA thus assumes that environmental risk management is, by a large part, determined by the competency of an organisation to manage the hazards associated with its' operations. OPRA is designed to enable the Agency to focus its attentions on the higher risks and worse performers, for example by informing the choices that managers make over how often front line regulators should visit premises and what they should look for. It may, in some circumstances, also help its officers to decide how much discretion they should apply during visits and how to balance their regulatory effort between issues (events occurring now) and risks (potential future issues). Initial work on OPRA provided valuable insight into the role of risk-based regulation, the choice of regulatory styles and tools, and the influence these can have on driving business behaviours.

3. The influence of risk-based environmental regulation

With respect to the development of risk-based regulation, regulated businesses have welcomed approaches that are risk-based – these are seen to make sound business sense (Confederation of British Industry, 1998; Confederation of British Industry, 1999). For good

operators, these initiatives are likely to result in investments that would be made anyway on the grounds of responsible corporate governance, and are thus supportable in scientific and business terms. The Agency's current operator performance assessment seeks to rank the maturity of an operator's environmental performance by reference to key attributes. Many regulated sectors (e.g. United Kingdom Offshore Operators Association, 1999) have risk-based approaches in place to guide operations, reduce business exposure and lessen business interruption losses. 'Best-in-class' organisations are better at managing risks wisely, learning from failure, and they exhibit resilience (robustness to shock) and agility (adaptive management and forward-looking) in response to an evolving business climate. Specifically, they balance business risk and opportunity in a mature fashion that ensures exposures are minimised and strategic competitive advantage is secured. Organisations competent in risk management recognise this maturity of capability is not secured solely through having risk frameworks, risk assessment manuals, audit trails, risk champions and risk registers in place. They assess their risk maturity (MacGillivray, 2008; IACCM, 2003) because it: (i) helps formalise their appetite for risk; (ii) makes more explicit the role of the group risk manager; (iii) provides opportunity for evaluating the implementation of risk management on the ground – that is, a reality check against high-level, corporate statements on risk; and (iv) it builds sustained corporate value. The risk management benchmarking tools now applied within high reliability sectors have value in the context of self-regulation for high performing sectors.

Securing evidence (Pollard, 2008) for the environmental outcomes mediated by modern regulation infers that causal links are established between regulatory style and environmental improvements (National Audit Office and Better Regulation Executive, 2007). Among the issues and observations raised by the Hampton implementation review of the Environment Agency's progress (Better Regulation Executive and National Audit Office, 2008)are that:

(i) the Environment Agency has made encouraging progress in implementing the Hampton principles;

(ii) better regulation is certainly in the language of the organisation, but not yet embedded throughout its culture;

(iii) there appears to be scope for OPRA to be used more effectively to incentivise compliance and inform risk-based interventions;

(iv) the Agency is currently unable to demonstrate a causal link between day-to-day regulatory activities and outcomes;

(v) it is not clear whether it is prioritising its resources on those sectors, emissions or activities which are most damaging to the environment" (para 95);

(vi) the quality and impact of inspections seems to depend on the competence and confidence of individual inspectors – some inexperienced staff appear to lack the confidence to exercise balanced risk-based judgements;

Establishing causality in this sense (iv, above) is not easily achieved given the confounding factors influencing environmental change and the multiple actors with this common interest. Weighted lines of evidence may support (or otherwise) the relationship between regulatory style and outcome (McPherson, 2008). Weight-of-evidence approaches (Krimsky, 2005) may use influence diagrams, evidential support logic, and Bayesian belief nets (Pourret, 2008; Schum, 1994) as visual aids to support the presentation of cause and effect. There is an established literature for weight of evidence assessments, developed in the fields of public health medicine (Hrudey, 2003), forensic science and radioactive waste management, with some applications to environmental risk and a history of using Bayesian methods, for example in the regulation of water utilities (O'Hagan, 2007). Individual environmental risk assessments frequently make use of data, concepts and assumptions for which a range of evidence of varying quality exists. In using assumptions to support risk assessments, risk

analysts frequently need to select between competing theories (e.g., low dose extrapolation), between a range of individual baseline studies (e.g., arsenic in drinking water) or from a palette of future environmental scenarios (e.g., climate change). Such analyses involve evaluating both complementary and potentially conflicting lines of reasoning, the direction and weight of which must be assessed in support of a specific qualitative or quantitative line of argument. Assembling such evidence within a framework of precaution, whilst also guided by requirements for proportionate levels of intervention, has long been a requirement of the safety cases prepared for radioactive waste disposal. Equally the approach has application to the management of exposures from engineering nanomaterials.

Alongside tools to integrate evidence, effective environmental decision making needs to face up squarely to key value tradeoffs. Value trade-offs are ubiquitous in regulation. Examples include the tradeoffs between efficacy, efficiency and equity, or public good and private profit, or in cases where regulatees face choices between visible and reassuring remediation strategies versus invisible but possibly more effective ones (monitored natural attenuation for contaminated groundwaters). For these decisions, the Environment Agency has been a sponsor of systematic multicriteria (or multiattribute) decision analysis (MCDA; Belton, 2002; Dodgson, 2000) which provide a framework within which value trade-offs can be made explicit. Agency guidance on best practicable option appraisal for radioactive waste disposal at nuclear sites (Environment Agency and Scottish Environment Protection Agency, 2004; Egan, 2002), for example, recommends nuclear operators undertake a participatory multicriteria appraisal exercise as part of the choice of disposal technology. The rationale offered is that this not only ensures the regulatee takes into account the views of local stakeholders in the technology choice, but that it also provides a framework for discussion between regulator and regulatee. This is in line with experience in other countries, where multicriteria approaches have been used in heavily regulated environments as a device to

make explicit and balance competing demands from a range of stakeholders, for example by energy companies BC Gas and BC Hydro in Canada (Keeney and McDaniels 1992; Hobbs and Horn 1997; Keeney and McDaniels 1999). However, there are a range of different philosophies of how MCDA (broadly conceived) should be applied, particularly for environmental applications (Renn, 1993; Gregory, 1992) and the question of what works best in a regulatory setting seems to be an open one.

Finally, as to the application of different regulatory styles, the adoption of a risk-based approach has enabled the Agency to engage with firms in a more responsive way that targets scarce regulatory resources on the higher risks and the worse performers. Although it could be argued that regulators have been using their discretionary powers to do this for many years, OPRA has given the Agency a more robust way of generating evidence on risk that can be used to support the adoption of different styles in a relatively clear, consistent and transparent way. When coupled with a similarly clear and transparent enforcement policy, this has enabled the Agency to adopt a sanctions-based regulatory style for the higher risks and worse performers (something called for by central government through the Hampton and Macrory Reports (Hampton, 2005; Macrory, 2006), and a more cooperative compliance-based approach for the lower risk and better performers (Gouldson, 2004). In theory (Ayres, 1994), such an approach can deliver more targeted and proportionate forms of regulation in a more consistent, transparent and accountable way, thereby satisfying the Government's principles for better regulation. It can also deliver efficiency gains for regulators, who are able to focus their resources more effectively, and for the more compliant operators who may be regulated less intensively. As long as the basis for risk-based decision making is communicated effectively, it could also enhance stakeholder trust in, and therefore the political acceptability of, environmental regulation.

This interactive aspect of regulation – the fact that one is dealing with a relatively small number of informed regulatees who have objectives of their own, and will respond to their perceptions of regulator behaviour - is one of the critical aspects of regulatory decision making. Understanding this complex relationship requires drawing on a range of insights from a number of academic disciplines. In public administration, for example, the idea of 'relational distance' has been helpful: the argument has been made, where inspectors are drawn from a different background from inspectees, that they are more likely to take a tough sanctions-based approach, and where they are drawn from a similar background, they are more likely to take a gentler compliance-based approach (Hood, 1999; Bevan, 2006). Formal approaches to examining this interaction, particularly in the area of monitoring and enforcement, have attracted attention from environmental economists in the UK and internationally, particularly in the US (see the extensive collection of readings in Russell 2003). Despite the volume of work on this issue, and attempts by such analysts in countries such as Germany (Avenhaus 1994) and Denmark (Hansen, Krarup and Russell 2006) to develop usable tools based around available practice and data, we are not aware of similar tools having been passed into routine operational use in day-to-day management in the UK.

4. Challenges with risk-based regulation

There is, therefore, an accumulation of experience in the design and application of risk based regulation in the Environment Agency and an ongoing programme of policy-oriented research that supports the Agency's initiatives in this field (Table 1). Although the outcomes of risk-based approaches have yet to be subjected to rigorous evaluation, there is a general belief that risk based approaches do lead to better regulatory outcomes.

When considered against the UK government's principles for better regulation, risk based approaches are seen as the main way of moving beyond a 'one size fits all' approach, and as

delivering more targeted forms of intervention. Drawing on the evidence base provided by new forms of risk assessment, risk based approaches are also seen to provide more proportionate forms of intervention. However, it is not yet explicitly clear that risk based approaches are applied by reference to the same set of overarching principles across different domains (*i.e.* the regulation of the different risks associated with climate change, flooding, radioactive waste, toxic pollution etc.), at different levels (i.e. senior managers taking strategic decisions, front-line managers taking operational decisions, front-line regulators taking 'street level' decisions) or in different sectoral (i.e. commercial, industrial, agricultural) or geographical areas of Agency operation. Furthermore, while schemes such as OPRA make the basis for regulatory decisions more transparent and accountable to regulatees, it is not yet clear that risk-based approaches have made regulatory activities more transparent and accountable to the public, despite Agency efforts to develop new forms of engagement and communication (Irving *et al.*, 2007).

When considered against the standard criteria for policy evaluation, it is assumed that risk based approaches lead to more efficient regulation, both for the public sector as scarce regulatory resources can be applied in a more targeted way and for the private sector as business burdens for the better performing firms and sites are reduced through lighter touch regulation. It is also hoped that it leads to more effective regulation as it increases the incentives for compliance through the prospect of lighter touch regulation, and the dis-incentives for non-compliance through the prospect of more intensive regulation and the imposition of higher sanctions. Because of these assumed incentives, risk based approaches are popular with politicians and businesses, but there has been some concern amongst broader stakeholder groups that better regulation actually means less regulation and that the distributional impacts of risk based approaches are not yet clear.

A fuller and more rigorous evaluation of the extent to which risk based approaches secure positive outcomes as measured against the criteria mentioned above would test these assumptions and strengthen the evidence base that underpins this aspect of Agency operations. It would provide critically important feedback to enable institutional learning within the Agency. By providing clear measures of performance, it could also enhance the transparency and accountability of, and therefore potentially build trust in, risk based approaches to regulation. Research to this effect is now underway within the Agency.

Related to the requirement for fuller and more rigorous evaluations of outcomes, there are a number of other more specific challenges facing the Environment Agency:

i) *Understanding best practice and promoting consistency in risk based regulation*

The Environment Agency is not alone in adopting risk-based approaches. Private sector organizations engaged in activities such as insurance, auditing and certification, technology supply and business development clearly have significant levels of expertise and experience. Regulators in other countries and in other domains also have relevant insights that could inform the development of a best practice model of risk regulation, perhaps most notably from the Health and Safety Executive. Potentially, both public and private sector bodies in the UK have data sets that could be combined to develop a more integrated risk regulation framework. The Environment Agency could benefit from reviewing other models of risk management and risk based regulation in such private and public organisations. Finally, there is a diversity of experience within the Agency that could be evaluated to develop a best practice model of risk-based regulation that could be applied more consistently across the Agency. Initiatives in all of these areas would help to convince the Agency's key constituencies and stakeholders that it understood and was consistently applying best practice in risk based regulation. A valuable initiative is the ongoing Agency research into

monitoring the effectiveness of risk-based decisions, and collation of Agency projects where risk-based decision-making has been at the heart of the decision process.

ii) *Developing reliable, responsive forms of risk assessment and monitoring*

Clearly risk-based approaches rely on risk assessments and on-going monitoring. Some measures of risk are routinely assessed and monitored in formalised processes that provide a transparent and defensible basis for risk-based decision making. However, other more subjective or experiential measures of risk are harder to measure in a formal way, and there are ill-defined issues about how different stakeholders might meaningfully participate, and how different forms of risk perception or tolerance should be taken into account. Equally unclear is the extent to which risk data is time and context specific, and whether existing forms of monitoring are sensitive enough to detect subtle but ultimately extremely important changes in risk management capacities or cultures in regulated firms. By developing new risk assessment and monitoring techniques that respond to these challenges, the Agency may be able to enhance the efficacy, efficiency and equitability of risk based approaches. A critical step forward has been the Agency's work on strategic risk assessment (Pollard, 2004) and its attempts to better characterize environmental harm through comparative risk assessment (Environment Agency, 2005). This ongoing risk policy research is likely to continue to inform the Agency's strategy and form the basis for assessments of efficacy and efficiency.

iii) Building capacities for responsive risk regulation

As well as requiring appropriate forms of monitoring, the Agency needs to build on its existing capacities for risk based decision making. Given the nature of the available evidence, the significance of uncertainty and ignorance and the range of sometimes competing risk perceptions, stronger and possibly more open, inclusive and accountable frameworks for multi-criteria or multi-attribute decision making are needed. One of the key

challenges here is to resolve the tensions between the need for rapid, responsive and evidence based forms of decision making and calls for more open, inclusive and deliberative forms of decision making. Trade-offs between the speed or efficiency, the quality or efficacy and the fairness or equitability of risk based decision making need to be better understood and addressed. Finally, the Agency will be challenged more and more to ensure that it has resources that can be rapidly redeployed, and the agility to switch between regulatory styles in response to changing levels of risk. By building its capacities to act in these ways, the Agency would be able to respond to the competing pressures that it commonly encounters in a well informed and balanced way.

iv) *Evaluating the influence of different regulatory styles*

While a limited body of research has considered the influence of national styles of regulation (Vogel, 1986; Gouldson, 2004) there has been little or no research on the influence that different regulatory styles can have when applied in combination. It is normally expected that a risk-based approach that regulates lower risks and better performers less intensively and that enables scarce resources to be redirected towards the higher risks and worse performers will, in aggregate, lead to more effective outcomes (i.e. lower overall levels of risk/better overall levels of environmental performance). However, it may be that the opposite is true; intensive scrutiny from regulators maybe the main driver of compliance in better performing firms, so lighter touch regulation may, over time, lead to lower levels of compliance amongst that category of firm; whilst intensive regulatory scrutiny may under some circumstances prevent the worse performing firms from developing the capacities and cultures needed to manage risks and improve performance. More research is needed on the extent to which different styles (and combinations of style) can build capacities, strengthen cultures and change behaviour in different types of regulated operator. This would enable

more targeted and tailored approaches to regulation to emerge that both improve environmental outcomes and reduce business burdens.

v) Understanding the role of the private sector

Increasingly, it is acknowledged that regulatory agencies do not have all of the powers, resources and information needed to regulate risks effectively. Indeed, some have suggested that we are witnessing a shift from state-centred regulation where powers are concentrated in regulatory bodies such as the Environment Agency to de-centred forms of governance, where powers are dispersed in broader networks of public, private and civic actors (Black, 2001; Gouldson, 2007). However, the range of roles that private actors such as insurers, consultants, trade associations, business development agencies and regulated firms can play in achieving public interest goals has yet to be fully investigated. A key issue is whether, and under what conditions, the Agency might transfer some of its responsibilities to the private sector. An obvious example relates to the role of private regulations such as environmental management systems standards, where the Agency has considered giving ISO14001 certified sites a lighter touch. However, research has questioned the extent to which ISO14001 guarantees improvements in environmental performance (Dahlström, 2003), and there are major concerns about the accountability of private sector organisations and about their capacity to regulate firms they have a commercial relationship with. Even where these can be addressed, there remain concerns about transaction costs and risk as it is not clear that basing aspects of the regulatory process on complex relationships between regulators and a potentially wide range of private actors would be any cheaper or more reliable than continuing to rely on the Agency to deliver risk based approaches. Being clear on this would enable the Agency to better understand when and under what conditions it may be appropriate to delegate some of its powers to private actors.

Conclusions

Risk based approaches are being widely employed within the better regulation agenda (OECD, 2006). They can be used to shape regulatory interventions and prioritise preventative controls (Department for Communities and Local Government, 2007), hopefully generating better (and in particular more effective and efficient) outcomes. Within this paper, we have reviewed existing experiences with risk-based approaches, but we have also highlighted some of the challenges that need to be addressed if risk-based approaches are to contribute fully to the realisation of modern or better regulation.

We adopt preventative risk management because we seek to avoid the unwarranted incidents that could lead to environmental harm. Though advocates of the benefits of risk-based regulation, we sound in closing a note of caution on what we perceive to be a creeping economic rationalism within regulation. When designed well, piloted and implemented with feedback, risk-based regulation can provide a sound basis for distinguishing greater risks from lesser ones, and for investing resources in risk management proportionate to the risks posed. However, it is important to acknowledge that these regulatory processes may also *incur* risk, unless the consequences of resource trade-offs are fully understood and, for certain consequences, guarded against. In other words, whilst risk-based approaches promise better regulation, if they prioritise efficiency over efficacy they also risk contributing to regulatory failure with potentially significant impacts on human health and the environment. We therefore suggest that risk-based approaches should be explored, but in a precautionary way where reductions in the efficacy or reliability of regulation are not risked in the pursuit of efficiency gains.

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REFERENCES

Avenhaus, R. Decision theoretic analysis of pollutant emission monitoring procedures. Annals of Operations Research 1994; 54: 23-38.

Ayres, I. and Braithwaite, J. Responsive regulation: Transcending the deregulation debate, (1994) Oxford OUP

Belton, V. and T. J. Stewart Multiple criteria decision analysis: an integrated approach. (2002) Boston, Kluwer

Better Regulation Executive and National Audit Office. Effective inspection and enforcement: implementing the Hampton vision in the Environment Agency, (2008) BRE and NAO, London, 48pp

Bevan, G. and Cornwell, J. Structure and logic of regulation and governance of quality of health care: was OFSTED a model for the Commission of Health Improvement? (2006) Health Economics, Policy and Law 1: 343-370

Black, J. Decentring regulation: understanding the role of regulation and self regulation in a "post-regulatory" world. (2001) Current Legal Problems 54, November, pp. 103-146

Confederation of British Industry. Shaping up: report of the environmental protection survey, (1999) CBI, London, 39pp

Confederation of British Industry. Worth the risk: improving environmental regulation, (1998) CBI, London, 23pp

Dahlström, K., Howes, C., Leinster, P. and Skea, J. Environmental management systems and company performance: assessing the case for extending risk-based regulation (2003) European Environment, 13(4): 187-203

Defra, Risk management strategy, (2002) Department for Environment, Food and Rural Affairs, London

Department for Communities and Local Government. The Future of building control, (2007) DCLG, London, 15pp. and the Pensions Regulator, Business plan 2006-2007 (2006), London, 33pp

Department of the Environment, A guide to risk assessment and risk management for environmental protection, (1995) HMSO, London, 92pp

Department of the Environment, Transport and the Regions (DETR), Risk assessment method for local air pollution control: A consultation paper; (2000) DETR: London, UK

Department of Environment, Transport and the Regions (DETR), Waste management licensing. Risk assessment inspection frequencies. 'OPRA for Waste'. A consultation paper; (1999) DETR: London, UK

DETR and the Environment Agency. Guidelines for environmental risk assessment and management, Revised Guidance, DETR, EA and Institute of Environmental Health, (2000) 88pp. The Stationery Office, London

Dodgson, J., Spackman, M. *et al.* Multicriteria analysis: a manual, (2000) http://www.communities.gov.uk/documents/corporate/pdf/146868

Egan, M. *et al.* Best practicable options for radioactive waste disposal at nuclear sites, (2002) Report P3-094, Environment Agency

Environment Agency, Informing strategic decisions with comparative risk assessment: a literature review. (2005) Science report RIS-05-01, Environment Agency, Bristol, ISBN 1 844 325 199, 46pp

Environment Agency, Operator and Pollution Risk Appraisal (OPRA), (1997) Version 2, Environment Agency, Bristol, 34pp

Environment Agency and Scottish Environment Protection Agency. Guidance for the Environment Agencies' Assessment of Best Practicable Environmental Option studies at nuclear sites, (2004) Environment Agency, Bristol

ESRC Global Environmental Change Programme, Risky choices, soft disasters. Environmental decision-making under uncertainty, (2000) University of Sussex, Brighton

European Commission, IMPEL Report: Minimum criteria for inspections – frequency of inspections; Implementation and Enforcement of Environmental Law (IMPEL) (1998) Network: Brussells, Accessed 1/5/01 at URL http://www.europe.eu.int/comm/environment/impel/reports

European Commission (2009) Third Strategic Review of Better Regulation in the European Union, European Commission communication, COM(2009)15, 28 January.

Gouldson, A. and Bebbington, J. Corporations and the governance of environmental risks, (2007) Environment and Planning C, Vol 25, Issue1, pp4-20

Gouldson, A. Cooperation and the capacity for control: regulatory styles and evolving influences of environmental regulation in the UK, (2004) Environment and Planning C, 22: 583-603

Gouldson, A. Cooperation and the capacity for control: Regulatory styles and the evolving influences of environmental regulation in the UK, (2004) Environment and Planning C, 22: 583-603

Green Alliance, Steps into uncertainty: Handling risk and scientific uncertainty, (2000) Green Alliance and ESRC Global Environmental Change Programme, available at www.green-alliance.org.uk/Publications

Gregory, R. Keeney, R. *et al*. Adapting the environmental-impact statement process to inform decision-makers. (1992) J. Policy Anal. Manage. 11(1): 58-75

Gunningham, N. and Grabosky, P. Smart regulation: Designing environmental policy, (1999) Clarendon Press

Halfacree, S. Pollution risk management, (1998) Issues in Environ. Sci. Technol. 9: 37-56

Hampton, P. Reducing administrative burdens: effective inspection and enforcement, (2005) HM Treasury, 147pp

Hampton, P. Reducing administrative burdens: effective inspection and enforcement, (2005) HM Treasury

Hansen, L. G., S. Krarup and C. S. Russell. Enforcement and Information Strategies. Journal of Regulatory Economics 2006; 30(1): 45-61.

Her Majesty's Inspectorate of Pollution, Operator and Pollution Risk Appraisal (OPRA), (1995) HMIP, London, 22pp

Her Majesty's Inspectorate of Pollution, The application of risk assessment and risk management to integrated pollution control, (1995) Centre for Integrated Environmental Risk Assessment, Report 1, HMIP, London, 59pp

Hobbs, B. F. and G. T. F. Horn. Building public confidence in energy planning: a multimethod MCDM approach to demand-side planning at BC gas. Energy Policy 1997; 25(3): 357-375.

Hood, C., James, O. *et al.* Regulation inside government: waste-watchers, quality police and sleazebusters, (1999) Oxford, OUP

House of Commons, The BSE enquiry, (2000) Volume 1: findings and conclusions; The Stationery Office: London

House of Lords, Select Committee on Science and Technology 1999-2000 (2000), 3rd report. Science and Society, HL Paper 38, The Stationery Office, London

House of Lords, Select Committee on Economic Affairs, (2006) 5th Report. Government policy of the management of risk, Volume 1, HL 183-I, The Stationery Office, London 40pp

Hrudey, S.E and Leiss, W. Risk management and precaution – insights on the cautious use of evidence. (2003) Environ. Health Persp. 111:1577-1581

IACCM, Organisational maturity in business risk management. The IACCM business risk management maturity model (BRM3), (2003) 14pp, Ridgefield, CT, USA

Interdepartmental Liaison Group on Risk Assessment, Risk assessment and risk management: Improving policy and practice within Government departments, 37pp, HSE Books, Suffolk

Irving, P., Bone, B., Hayes, E., Colvin, J., Irwin, J., Stilgoe, J. and Jones, K. A people's inquiry on nanotechnology and the environment, (2007) Science Report SCHO0607BMUJ-E-P. Environment Agency, Bristol.

OECD (2005) Guiding Principles for Regulatory Quality and Performance, Organisation for Economic Cooperation and Development, Paris.

Keeney, R. L. and T. L. McDaniels. Value-focused thinking about strategic decisions at BC Hydro. Interfaces 1992; 22(6): 94-109.

Keeney, R. L. and T. L. McDaniels. Identifying and structuring values to guide integrated resource planning at BC Gas. Operations Research 1992; 47(5): 651-662.

MacGillivray, B.H. and Pollard, S.J.T. What can water utilities do to improve risk management within their business functions? An improved tool and application of process benchmarking, (2008) Environ. Intl., in press

Macrory, R. Regulatory justice: making sanctions effective, (2006) Cabinet Office Better Regulation Executive

McPherson, C. *et al.* The importance of benthos in weight-of-evidence sediment assessments – a case study, (2008) Sci. Tot. Environ. 394: 252-264

National Audit Office and Better Regulation Executive, Hampton implementation reviews: Guidance for review teams, (2007) NAO and BRE, London, 30pp

OECD, Risk and regulation: issues for discussion. (2006) Working Party on Regulatory Management and Reform. Public Governance Committee, Public Governance and Territorial Development Directorate, OECD, Paris, Paper GOV/PGC/REG(2006)1, 26pp

O'Hagan, A. The ABLE story: Bayesian asset management in the water industry. The practice of Bayesian analysis. (1997) S. French and J. Q. Smith. (eds) London, Arnold

OXERA, Policy, risk and science: Securing and using scientific advice. (2000) Contract Research Report 295/2000. HSE Books, Sudbury (at: www.hse.gov.uk/research)

Parliamentary Office of Science and Technology (POST) Safety in Numbers? Risk Assessment in Environmental Protection, (1996) POST, London,

Pollard, S.J.T. An overview of the use of risk assessment for environmental regulation in the UK – key drivers and regulatory initiatives, (2001) Risk, Decision & Policy 6: 33-46

Pollard, S.J.T., Davies, G.J., Coley, F. and Lemon, M. Better environmental decision-making – recent progress and future trends, (2008) Sci. Tot. Environ., in press

Pollard, S.J.T., Kemp, R.V., Crawford, M. Duarte-Davidson, R. Irwin, J.G. and Yearsley, R. Characterising environmental harm: developments in an approach to strategic risk assessment and risk management, (2004) Risk Anal., 24(6): 1551-1560

Pollard, S.J.T., Yearsley, R., Reynard, N., Meadowcroft, I.C., Duarte-Davidson, R. and Duerden, S. Current directions in the practice of environmental risk assessment in the United Kingdom, (2002) Environ. Sci. Technol. 36(4):530-538

Pourret, O., Naïm, P. *et al.* Bayesian networks: A practical guide to applications (2008), Wiley-Blackwell

Renn, O., Webler, T. *et al.* Public participation in decision making: a three-step procedure. (1993) Policy Science 26: 189-214

Rothstein, H., Irving, P., Walden, T. and Yearsley, R. (2006) The risks of risk-based regulation: insights from the environmental policy domain, Environment International 32: 1056-1065.

Russell, C. S., Ed. (2003). The Economics of Environmental Monitoring and Enforcement. The international library of environmetal economics and policy. Ashgate, Aldershot, 2003, 573 pp.

Schum, D.A. The evidential foundations of probabilistic reasoning, (1994) Chichester, Wiley

Strategy Unit, Risk: Improving Government's capability to handle risk and uncertainty, (2002) The Strategy Unit, London, 134pp

United Kingdom Offshore operators Association, (1999) Industry Guidelines on a Framework for Risk Related Decision Support; United Kingdom Offshore Operators Association: London, UK

Vogel, D. National Styles of regulation: Environmental policy in Great Britain and the United States, (1986) Cornwall University Press

1 Table 1 Recent Agency-funded research on risk-based regulation

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Research question	Addressed by	Report number	Date
How should we manage conflicts in expert opinion on risk?	Understanding risk cultures. Supporting consistency in environmental risk assessment. CEH workshop report.	E2-064	2002
What opportunities exist to align risk-based regulation with corporate initiatives on business risk management?	Dames and Moore review of current initiatives in corporate risk management	E2-056	2002
How should we compare environmental risks of strategic importance?	Reviews and methodology for strategic and comparative risk assessment. National Centre for Risk Analysis and Options Appraisal-Galson Sciences case studies. Review of comparative risk assessment tools	E2-041 SC050030	2002 2007
How is operator environmental performance and environmental risk are recognised in the regulatory	Article 10 of the revised Eco-management and Audit Scheme regulation requires member states to take steps to ensure that the work of EMAS verifiers and the regulators is not duplicated. This report indicates what work has been undertaken in other member states in this regard.	P6-005	2002
How sound are the Agency's environmental / business risk criteria in order to ensure its practicality, robustness and credibility	Tenaco Limited report.	E2-055	2003
Does societal concern lead policy makers to develop more stringent risk management objectives and standards?	Report of a one-day workshop	SC030032	2004
How do the characteristics, functions and approaches to influencing used by special interest groups impact of the Agency's work?	University of Surrey. Study aims to assist staff, particularly at the local level, to engage effectively with them as a part of their regular activities and around contentious issues	SC020067	2004
How should we involve stakeholders in risk assessment-risk management decisions?	National Centre for Risk Analysis and Options Appraisal - University of Birmingham study	SC000009	2004
What do internal Agency staff understand by risk-based regulation?	Environmental Policy, Risk and Forecasting internal questionnaire	Internal audience only	2007
Does risk-based compliance assessment support the principles of modern regulation?	RMC study and case study report	SC040042	2007
What futures might the Agency utilise to evaluate its own business risks against?	A set of four (updateable and risk-based) scenarios (for the 2050s) for the Environment Agency to improve the robustness of its future planning by providing a credible, consistent tool to aid decision making processes that will be supported by a set of robust indicators.	SC050002	2007
Can we secure better, more effective risk-based decision-making?	Cranfield University and Environmental Policy study. Methodology developed for assessing flagship risk-based decisions in Agency in response to Hampton Implementation Review.	SC070055	ongoing

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