for potable water also needs to be evaluated to determine how much should be spent to ensure microbiological safety and integrity of the distribution system.

To understand the long-term properties of water distribution systems, comparative data are needed on water quality, disease outbreaks, and distribution system failures from all approaches used to produce potable water. The water microbiome in distribution pipes and the definition of microbiologically safe water should be further investigated. In addition, improved monitoring and emerging sensor technology can provide warnings and alerts, helping to determine when to restore and protect extensive pipe assets. In the case of green water infrastructure, which includes water recycling, rainwater harvesting, and solar water heating, multiple barriers will be necessary to prevent opportunistic pathogens such as *Legionella*, which is higher in buildings with green water designs and longer water residence times (*15*). But the European evidence to date suggests that safe water can indeed be delivered without a disinfectant residual, as long as there are multiple barriers in operation. ■

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WATER

Saving freshwater from salts

Ion-specific standards are needed to protect biodiversity

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Many human activities—like agriculture and resource extraction—are increasing the total concentration of dissolved inorganic salts (i.e., salinity) in freshwaters. Increasing salinity can have adverse effects on human health (*1*); increase the costs of water treatment for human consumption; and damage infrastructure [e.g., amounting to $700 million per year in the Border Rivers catchment, Australia (*2*)]. It can also reduce freshwater biodiversity (*3*); alter ecosystem functions (*4*); and affect economic well-being by altering ecosystem goods and services (e.g., fisheries collapse). Yet water-quality legislation and regulations that target salinity typically focus on drinking water and irrigation water, which does not automatically protect biodiversity.

POLICY

For example, specific electrical conductivities (a proxy for salinity) of 2 mS/cm can be acceptable for drinking and irrigation but could extirpate many freshwater insect species (*3*). We argue that salinity standards for specific ions and ion mixtures, not just for total salinity, should be developed and legally enforced to protect freshwater life and ecosystem services. We identify barriers to setting such standards and recommend management guidelines.

Attempts to regulate salinization on the basis of ecological criteria can be found in the United States and Australia, where total salinity recommendations have been made (*5*, *6*). Even these criteria are insufficient to protect freshwater life, because waters with the same total amount of salts but different ionic composition can have markedly different effects on freshwater fauna (*7*). Canada and the United States are the only countries in the world that identify concentrations of a specific ion (chloride) above which freshwater life will be harmed (*6*, *8*). Globally, concentrations of other ions (e.g., Mg^{2+}, HCO_3^-) remain free from regulation in spite of their potential toxicity (*9*).

The situation will likely worsen in the future, because predicted increase in demand for freshwater will reduce the capacity of surface waters to dilute salts, and increasing resource extraction and other human activities (*10*) will generate additional saline effluents and runoff. Climate change will likely exacerbate salinization by causing seawater intrusion in coastal freshwaters, increasing evaporation, and reducing precipitation in some regions (*11*).

SETTING STANDARDS. Scientific understanding of mechanisms by which increasing salinization damages freshwater ecosystems is in its infancy, which makes it challenging to develop and implement standards protective of freshwater life. Technical challenges are exacerbated by the fact that salinization risks perceived by the public and policy-makers may be much lower than those identified by scientists. In addition, although scientific input has been

Wetland salinization. Feeder creek at Bottle Bend Lagoon, a wetland near Midura, Australia, where inadequate water management in the past has led to salinization and acid sulfate soils.

used to set standards, there has been inadequate integration of costs of salinity and benefits of controls.

Several countries have specific requirements for developing and implementing water-quality standards, e.g., the Australian and New Zealand Environmental and Conservation Council (ANZECC), the Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ), the Clean Water Act in the United States, and the Water Framework Directive and related legislation in the European Union. We draw on these experiences and recommend an integrated approach to standards development and management that includes a triple bottom line (TBL) approach, a well-established framework with multiple stakeholder input used to account for social, economic, and environmental impacts of management options. This should produce ecologically meaningful and protective salinity standards for any jurisdiction, although the amount of work needed will vary widely depending on available data and existing regulatory structures. Components are the following.

(i) *Characterize water bodies to which standards will apply.* Freshwaters naturally vary in ionic concentrations and composition because of underlying geology, proximity to the ocean, and hydrology (3). Protecting organisms adapted to widely differing ion concentrations will require locality-specific standards based on natural background ion concentrations. Such conditions can now be estimated for any water body, which makes site-specific standards possible (*12*).

(ii) *Characterize ionic composition (i.e., concentrations of specific ions and their ratios) of effluents associated with each existing driver of salinization in the region.* Also, assess the technical potential to reduce effluent loads and total flows and the social and economic impacts associated with these reductions.

(iii) *Quantify potential effects of each class of saline effluent in the region and identify thresholds for toxic effects.* Quantifying relationships between biota and ionic composition from field survey data can help identify taxa at potential risk and prioritize toxicity experiments. As with other contaminants, both laboratory bioassays (e.g., lethal concentration 50 or whole-effluent toxicity tests) and longer-term mesocosm experiments should be used to quantify toxicity of different ions to a representative set of species (e.g., fish, amphibians, invertebrates, and algae).

(iv) *Ensure that standards are informed by the best available science and understanding of costs and benefits.* Stakeholder involvement is crucial to ensuring that arrangements will be implemented and enforced in practice (*13*). This process needs to be structured to promote communication and social learning across different constituencies, so as to ensure that scientific results are understandable by policy-makers, affected stakeholders, and the public. Sound integration of insights from natural and social sciences will help all parties understand the risks and opportunities of different options for protec-

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tion and restoration. Such analyses should be based ideally on state-of-the-science techniques of decision support and benefit-cost analysis that account for the diversity of societal values (including market and nonmarket values) associated with the causes and consequences of salinization. Given that evidence will improve, developing standards and wider governance arrangements will require an iterative approach over time. The Australian Murray-Darling Basin salinity management strategy (*14*) is an example of how planning and consultation can lead to catchment-specific salinity targets. This strategy sits within the overall Murray-Darling Basin Plan, where legislation requires a TBL approach.

MANAGEMENT MEASURES. Several management actions could help meet existing and emerging standards and could prevent or remediate damage associated with freshwater salinization. Essential to all of these options is providing incentives for reducing salinization, such as by market-based instruments, subsidies for technology development and implementation, or load-based charges on saline effluents. Examples of good practices include the following.

(i) *Implement agriculture practices that use less water and thereby reduce salt loading to freshwaters.* For example, the Colorado River Basin Salinity Control Program has reduced salt loading to the river by an estimated 1.3 million tons/year, mostly by improving irrigation practices (*15*).

(ii) *Reduce or eliminate the use of salts as pavement deicers by making more effective application and use of the salts that are applied or by using alternative deicers.*

(iii) *Reduce point-source production and discharge of salts to freshwaters.* For example, innovative methods of resource extraction that sequester soluble minerals away from water sources have potential to reduce effluent discharge to streams.

(iv) *Implement cap-and-trade schemes.* This cost-effective approach is being used in Australia (e.g., the Hunter River Salinity Trading Scheme), where miners and power generators trade permits to discharge salt-rich effluents during moderate to high flow periods.

(v) *Develop specific management options for salt-rich effluents.* Salt-rich urban discharges could be routed to retention basins rather than treatment plants or streams. Although currently prohibitively expensive, water desalinization may become a viable treatment, particularly solar-powered systems, such as are in development in the Middle East. Recovering salts could reduce costs, e.g., using magnesium to recover ammonia and phosphate in the form of struvite, which has commercial value.

(vi) *Promote practices that reduce salinization.* Recognition of water-wise products (e.g., via eco-labels) or support for direct economic incentives to commercialize crops that demand less water (*14*) can be useful tools to alter behaviors.

Fortunately, few large-scale ecological disasters have been caused by salinization of freshwater ecosystems to date, but those that have [e.g., the fisheries collapse in the Aral Sea in Central Asia (*16*)] should be a wake-up call. International cooperation and scientific knowledge-sharing are needed to develop solutions that can be applied globally. Experiences like those near the river Werra in Germany, where a combination of total ion and ion-specific discharge requirements led to ecosystem recovery (*17*), show that rehabilitation of salt-polluted freshwater ecosystems is possible. Prevention of salt damage is much more likely if water managers, stakeholders, and scientists work together to identify social, economic, and ecological costs and the benefits that can accrue from prevention and restoration. ■

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DNA

Breaking DNA

A long-sought protein that helps to break DNA is finally discovered

By **Corentin Claeys Bouuaert** and **Scott Keeney**

To maintain a constant number of chromosomes from one generation to the next, sexual organisms reduce the genome complement in their gametes through the specialized cellular division of meiosis. Accurate separation of homologous chromosomes during meiosis relies on a dedicated mechanism of DNA recombination that is initiated by DNA double-strand breaks (DSBs) made by a protein called sporulation protein 11 (Spo11) (*1*). Meiotic recombination helps connect homologous chromosomes to promote their accurate segregation, and also shuffles alleles between homologous chromosomes to increase diversity. Spo11 is encoded in nearly all sequenced eukaryotic genomes, and it is likely that most species that carry out meiotic recombination use Spo11-generated DSBs as the initiators (*2*). Spo11 is thus an ancient and fundamental part of sexual reproduction. On pages 939 and 943 of this issue, Vrielynck *et al.* (*3*) and Robert *et al.* (*4*) report the discovery of a long-sought partner of Spo11 in plants and mice, respectively.

"...meiotic cells play the risky game of forming a great deal of...self-inflicted DNA damage..."

Spo11 evolved from an ancestral type II DNA topoisomerase (Topo VI) that is found today in Archaea and a few eukaryotic lineages, including some plants (*2*). Topoisomerases create transient breaks in DNA to change DNA supercoiling or untangle intertwined DNA duplexes, thereby facilitating processes such as transcription or replication. Topo VI comprises two "A" subunits that cleave DNA and two "B" sub-

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