

A woman with dark hair, wearing a grey sweater and a blue apron, is carrying a wooden yoke across her shoulders. The yoke has two large metal buckets hanging from it. She is walking on a rocky, uneven path. In the background, another person wearing a white hat and a dark jacket is also carrying a yoke with buckets. The scene is set in a rugged, rocky environment.

The  
Economist

# For want of a drink

A special report on water | May 22nd 2010

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# For want of a drink

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It won't fill up without lots of changes on the ground—and much greater restraint by users. Page 15

#### Conversions

1 litre =	0.26 US gallons
1 cubic metre =	264 US gallons
1 hectare =	2.47 acres
1 km =	0.62 miles

#### Acknowledgments

Of the many people who helped in the preparation of this report, the author would like to give special thanks to: Julia Bucknall of the World Bank, Chander Parkash of Khethi Virasat, P. Somasekhar Rao of the Food and Agriculture Organisation, the Rev V. Paul Raja Rao of the Bharati Integrated Rural Development Society, and Dai Qing.

A list of sources is at

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Finite, vital, much wanted, little understood, water looks unmanageable. But it needn't be, argues John Grimond

WHEN the word water appears in print these days, crisis is rarely far behind. Water, it is said, is the new oil: a resource long squandered, now growing expensive and soon to be overwhelmed by insatiable demand. Aquifers are falling, glaciers vanishing, reservoirs drying up and rivers no longer flowing to the sea. Climate change threatens to make the problems worse. Everyone must use less water if famine, pestilence and mass migration are not to sweep the globe. As it is, wars are about to break out between countries squabbling over dams and rivers. If the apocalypse is still a little way off, it is only because the four horsemen and their steeds have stopped to search for something to drink.

The language is often overblown, and the remedies sometimes ill conceived, but the basic message is not wrong. Water is indeed scarce in many places, and will grow scarcer. Bringing supply and demand into equilibrium will be painful, and political disputes may increase in number and intensity in their capacity to cause trouble. To carry on with present practices would indeed be to invite disaster.

Why? The difficulties start with the sheer number of people using the stuff. When, 60 years ago, the world's population was about 2.5 billion, worries about water supply affected relatively few people. Both drought and hunger existed, as they have throughout history, but most people could be fed without irrigated

farming. Then the green revolution, in an inspired combination of new crop breeds, fertilisers and water, made possible a huge rise in the population. The number of people on Earth rose to 6 billion in 2000, nearly 7 billion today, and is heading for 9 billion in 2050. The area under irrigation has doubled and the amount of water drawn for farming has tripled. The proportion of people living in countries chronically short of water, which stood at 8% (500m) at the turn of the 21st century, is set to rise to 45% (4 billion) by 2050. And already 1 billion people go to bed hungry each night, partly for lack of water to grow food.

People in temperate climates where the rain falls moderately all the year round may not realise how much water is needed for farming. In Britain, for example, farming takes only 3% of all water withdrawals. In the United States, by contrast, 41% goes for agriculture, almost all of it for irrigation. In China farming takes nearly 70%, and in India nearer 90%. For the world as a whole, agriculture accounts for almost 70%.

Farmers' increasing demand for water is caused not only by the growing number of mouths to be fed but also by people's desire for better-tasting, more interesting food. Unfortunately, it takes nearly twice as much water to grow a kilo of peanuts as a kilo of soyabean, nearly four times as much to produce a kilo of beef as a kilo of chicken, and nearly five times as much to produce a glass of orange juice as a cup of

► tea. With 2 billion people around the world about to enter the middle class, the agricultural demands on water would increase even if the population stood still.

Industry, too, needs water. It takes about 22% of the world's withdrawals. Domestic activities take the other 8%. Together, the demands of these two categories quadrupled in the second half of the 20th century, growing twice as fast as those of farming, and forecasters see nothing but further increases in demand on all fronts.

### That's your lot

Meeting that demand is a different task from meeting the demand for almost any other commodity. One reason is that the supply of water is finite. The world will have no more of it in 2025, or 2050, or when the cows come home, than it has today, or when it lapped at the sides of Noah's ark. This is because the law of conservation of mass says, broadly, that however you use it, you cannot destroy the stuff. Neither can you readily make it. If some of it seems to come from the skies, that is because it has evaporated from the Earth's surface, condensed and returned.

Most of this surface is sea, and the water below it—over 97% of the total on Earth—is salty. In principle the salt can be removed to increase the supply of fresh water, but at present desalination is expensive and uses lots of energy. Although costs have come down, no one expects it to provide wide-scale irrigation soon.

Of the 2½% of water that is not salty, about 70% is frozen, either at the poles, in glaciers or in permafrost. So all living things, except those in the sea, have about 0.75% of the total to survive on. Most of this available water is underground, in aquifers or similar formations. The rest is falling as rain, sitting in lakes and reservoirs or flowing in rivers where it is, with luck, replaced by rainfall and melting snow and ice. There is also, take note, water vapour in the atmosphere.

These geophysical facts affect the use of language in discussions about water, and the ways in which to think about the problems of scarcity. As Julia Bucknall, the World Bank's water supremo, points out, demand and supply are economic concepts, which the matchmakers of the dismal science are constantly trying to bring into balance. In the context of water, though, supply is also a physical concept and its maximum is fixed.

Use is another awkward word. If your car runs out of petrol, you have used a tankful. The petrol has been broken down

and will not soon be reconstituted. But if you drain a tank of water for your shower, have you used it? Yes, in a sense. But could it not be collected to invigorate the plants in your garden? And will some of it not then seep into the ground to refill an aquifer, or perhaps run into a river, from either of which someone else may draw it? This water has been used, but not in the sense of rendered incapable of further use. Water is not the new oil.

However, there are some "uses" that leave it unusable for anyone else. That is either when it evaporates, from fields, swimming pools, reservoirs or cooling towers, or when it transpires, in the photosynthetic process whereby water vapour passes from the leaves of growing plants into the atmosphere. These two processes, known in combination as evapotranspiration (ET), tend to be overlooked by water policymakers. Yet over 60% of all the rain and snow that hits the ground cannot be captured because it evaporates from the soil or transpires through plants. Like water that cannot be recovered for a specific use because it has run into the sea or perhaps a saline aquifer, water lost through ET is, at least until nature recycles it, well and truly used—or, in the language of the water world, "consumed", ie, not returned to the system for possible reuse.

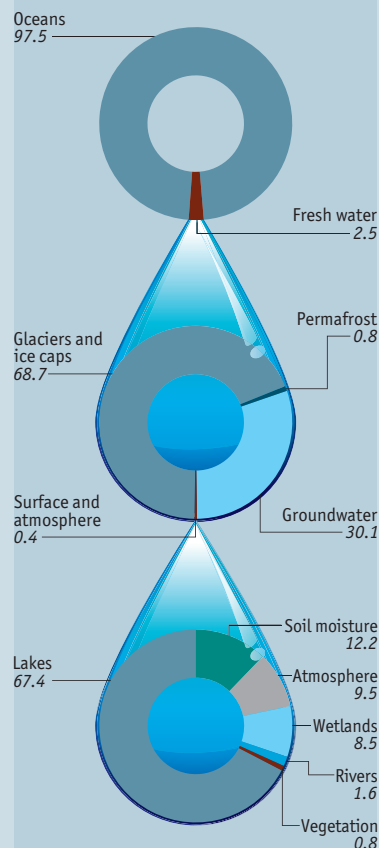
The problems caused by inexact terminology do not end here. Concepts like efficiency, productivity and saving attract woolly thinking. Chris Perry, an irrigation economist widely considered the high priest of water accounting, points out that "efficient" domestic systems involve virtually no escape of water through evaporation or irrecoverable seepage. "Efficient" irrigation, though, is often used to describe systems that result in 85% of the water disappearing in vapour. Similarly, water is not saved by merely using less of it for a purpose such as washing or irrigation; it is saved only if less is rendered irrecoverable.

### Soaked, parched, poached

Many of these conceptual difficulties arise from other unusual aspects of water. It is a commodity whose value varies according to locality, purpose and circumstance. Take locality first. Water is not evenly distributed—just nine countries account for 60% of all available fresh supplies—and among them only Brazil, Canada, Colombia, Congo, Indonesia and Russia have an abundance. America is relatively well off, but China and India, with over a third of the world's population between them, have less than 10% of its water.

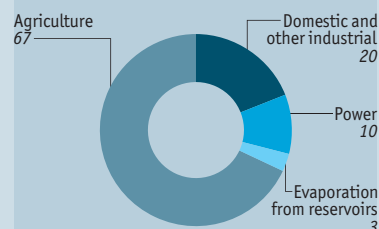
## Where the water comes from...

Global water resources, %

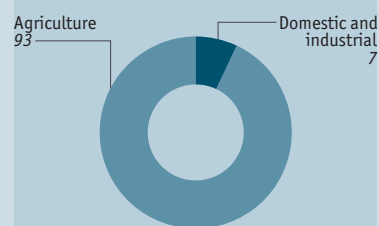


## ...and where it goes

Water abstraction from rivers, lakes and groundwater, %



Consumptive use\* of abstracted water, %



Source: World Bank: *World Development Report 2010*

\*Water unavailable for further use in the system



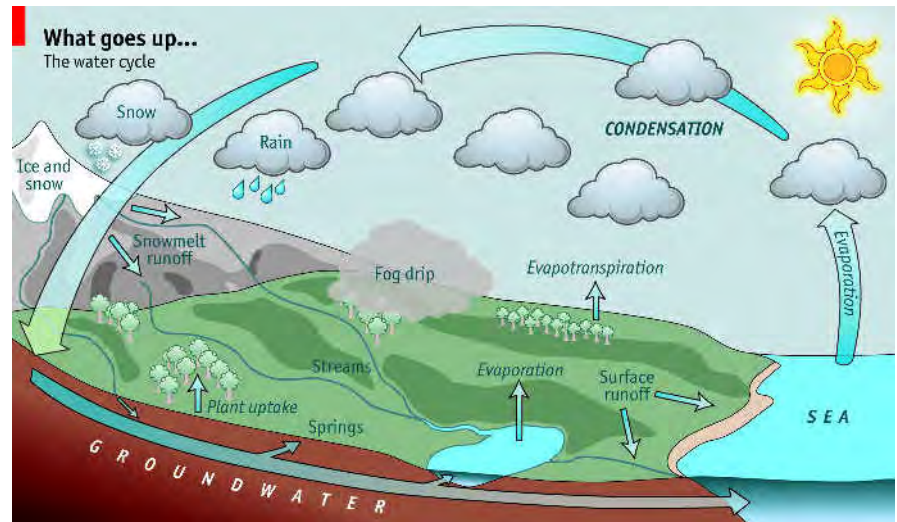
Even within countries the variations may be huge. The average annual rainfall in India's north-east is 110 times that in its western desert. And many places have plenty of water, or even far too much, at some times of year, but not nearly enough at others. Most of India's crucial rain is brought by the summer monsoon, which falls, with luck, in just a few weeks between June and September. Flooding is routine, and may become more frequent and damaging with climate change.

Scarce or plentiful, water is above all local. It is heavy—one cubic metre weighs a tonne—so expensive to move. If you are trying to manage it, you must first divide your area of concern into drainage basins. Surface water—mostly rivers, lakes and reservoirs—will not flow from one basin into another without artificial diversion, and usually only with pumping. Within a basin, the water upstream may be useful for irrigation, industrial or domestic use. As it nears the sea, though, the opportunities diminish to the point where it has no uses except to sustain deltas, wetlands and the estuarial ecology, and to carry silt out to sea.

These should not be overlooked. If rivers do not flow, nothing can live in them. Over a fifth of the world's freshwater fish species of a century ago are now endangered or extinct. Half the world's wetlands have also disappeared over the past 100 years. The point is, though, that even within a basin water is more valuable in some places than in others.

Almost anywhere arid, the water underground, once largely ignored, has come to be seen as especially valuable as the demands of farmers have outgrown their supplies of rain and surface water. Groundwater has come to the rescue, and for a while it seemed a miraculous solution: drill a borehole, pump the stuff up from below and in due course it will be replaced. In some places it is indeed replenished quite quickly if rain or surface water is available and the geological and soil conditions are favourable. In many places, however, from the United States to India and China, the quantities being withdrawn exceed the annual recharge. This is serious for millions of people not just in the country but also in many of the world's biggest cities, which often depend on aquifers for their drinking water.

The 20m inhabitants of Mexico City and its surrounding area, for example, draw over 70% of their water from an aquifer that will run dry, at current extraction rates, within 200 years, maybe much sooner. Already the city is sinking as a re-



sult. In Bangkok, Buenos Aires and Jakarta, the aquifers are similarly overdrawn, polluted or contaminated by salt. Just as serious is the depletion of the aquifers on which farmers depend. In the Hai river basin in China, for example, deep-groundwater tables have dropped by up to 90 metres.

Part of the beauty of the borehole is that it requires no elaborate apparatus; a single farmer may be able to sink his own tubewell and start pumping. That is why India and China are now perforated with millions of irrigation wells, each drawing on a common resource. Sometimes this resource will be huge: the High Plains aquifer, for example, covers 450,000 square kilometres below eight American states and the Guaraní aquifer extends across 1.2m square kilometres below parts of Argentina, Brazil, Paraguay and Uruguay. But even big aquifers are not immune to the laws of physics. Parts of the High Plains are seriously overdrawn. In the United States, China and many other places, farmers probably have to pay something for the right to draw groundwater. But almost nowhere will the price reflect scarcity, and often there is no charge at all and no one measures how much water is being taken.

#### Liquid asset or human right?

Priced or not, water is certainly valued, and that value depends on the use to which it is harnessed. Water is used not just to grow food but to make every kind of product, from microchips to steel girders. The largest industrial purpose to which it is put is cooling in thermal power generation, but it is also used in drilling for and extracting oil, the making of petroleum products and ethanol, and the production of hydro-electricity. Some of the processes involved, such as hydro power generation, consume little water (after driving the turbines, most is returned to the river), but some, such as the techniques used to extract oil from sands, are big consumers.

Industrial use takes about 60% of water

in rich countries and 10% in the rest. The difference in domestic use is much smaller, 11% and 8% respectively. Some of the variation is explained by capacious baths, power showers and flush lavatories in the rich world. All humans, however, need a basic minimum of two litres of water in food or drink each day, and for this there is no substitute. No one survived in the ruins of Port-au-Prince for more than a few days after January's earthquake unless they had access to some water-based food or drink. That is why many people in poor and arid countries—usually women or children—set off early each morning to trudge to the nearest well and return five or six hours later burdened with precious supplies. That is why many people believe water to be a human right, a necessity more basic than bread or a roof over the head.

From this much follows. One consequence is a widespread belief that no one should have to pay for water. The Byzantine emperor Justinian declared in the sixth century that "by natural law" air, running water, the sea and seashore were "common to all". Many Indians agree, seeing groundwater in particular as a "democratic resource". In Africa it is said that "even the jackal deserves to drink".

A second consequence is that water often has a sacred or mystical quality that is invested in deities like Gong Gong and Osiris and rivers like the Jordan and the Ganges. Throughout history, man's dependence on water has made him live near it or organise access to it. Water is in his body—it makes up about 60%—and in his soul. It has provided not just life and food but a means of transport, a way of keeping clean, a mechanism for removing sewage, a home for fish and other animals, a medium with which to cook, in which to swim, on which to skate and sail, a thing of beauty to provide inspiration, to gaze upon and to enjoy. No wonder a commodity with so many qualities, uses and associations has proved so difficult to organise. ■

# Enough is not enough

It must also be clean

**I**F WATER has the capacity to enhance life, its absence has the capacity to make it miserable. David Gray, a water practitioner who has served the World Bank in almost every river basin on the globe and is now a professor at Oxford, has a technique that makes the point. Every day he receives e-mails with water stories from newspapers round the world. By briefly displaying to an audience just one day's crop—including, say, drought in Australia, floods in Kenya, an empty dam in Pakistan, a toxic spill in the Yellow river and saltwater contamination in Haiti—he can soon show how water may dominate if not destroy lives, especially in poor countries.

Some of its most pernicious influences, though, never make the headlines. This is how they might read: "Over 1.2 billion people have to defecate in the open." "The biggest single cause of child deaths is diarrhoea or diseases related to it." "Nearly 1 billion people have no access to piped drinking water or safe taps or wells." Each of these statements is linked to water.

Surprisingly, some of those who have to defecate in the open do not mind. Some rural men, and even women, quite enjoy a social squat in the bushes. But for many, and certainly for those who must live with its consequences, it is a disagreeable practice. Women and, especially, girls often find it embarrassing. Many women in South Asia contain themselves by day and wait till nightfall before venturing into the shadows. Girls at African schools without latrines often drop out rather than risk the jeers of their male contemporaries. Slum-dwellers in Nairobi have to pick their way through streams of sewage and take care to avoid "flying toilets", plastic bags filled with excrement that are flung with desperate abandon into the night.

Without piped water to wash their hands with, let alone to drink, the open-air defecators and another 800m people with access only to primitive latrines are inevitably carriers of disease. If they could wash their hands with soap and water, they could block one of the main transmission routes for the spread of both diarrhoeal diseases and respiratory infections. As it is, patients with water-related diseases fill half the hospital beds in the poor-

est countries, and dirty water and poor sanitation kill 5,000 children a day.

Clean water is crucial for children with diarrhoea; they need rehydration and electrolytes to survive. Even then, they may still be at risk of malnutrition if they continue to suffer from diarrhoea, which will prevent them from absorbing their food properly. This usually has long-term consequences. Malnutrition in the womb and during the first two years of life is now seen as causing irreversible changes that lead to lifelong poor health.

Poor health, bad in itself, translates into poor economic output. A study in Guatemala followed the lives of children in four villages from their earliest years to ages between 25 and 42. In two villages the children were given a nutritious supplement for their first seven years, and in the other pair a less nutritious one. The boys who had had the more nutritious diet in their first two years were found to have larger bodies, a greater capacity for physical work, more schooling and better cognitive skills. They also grew up to earn average wages 46% higher than the other groups.

## The cost to health and wealth

Studies in Ghana and Pakistan suggest that the long-term impact of malnutrition associated with diarrhoeal infections costs each country 4-5% of GDP. This can be added to a similar burden for "environmental risk", which includes malaria and poor access to water and sanitation, both water-related, as well as indoor air pollution. All in all, the World Health Organisation thinks that half the consequences of malnutrition are caused by inadequate water, sanitation and hygiene. In Ghana and Pakistan the total cost of these shortcomings may amount to 9% of GDP, and these two countries are not unique.

The problem is not strictly a matter of water scarcity. Indeed, expanding the availability of water may actually increase disease, since it may lead to stagnant pools in which mosquitoes breed, and then spread malaria or dengue fever; or perhaps excess water will run through human or toxic waste and thus contaminate the ground or a nearby stream. So hygiene and protected storage are essential.

Yet there is a shortage of safe water for drinking and sanitation in many places, not least in the cities to which so many people are now flocking. Africa is urbanising faster than any other continent, and most migrants to the towns there find themselves living in slums. In cities like Addis Ababa and Lagos a quarter to a half of the population have no access to decent sanitation, and not many more will have access to piped water. No Indian city has a 24-hour domestic water supply, though efforts are under way to provide it in Mysore and a few other places.

Delhi's story is typical. Demand for water there has been rising for years. The local utility cannot meet it. The city's pipes and other equipment have been so poorly maintained that 40% of the supply fails to reach the customers. So the utility rations it by providing water for a limited number of hours a day and, in some places, by restricting the quantity. Householders and landlords build tanks, if they can, and fill them when the water is available. Residents, or their weary employees, set their alarm clocks to turn on the tap before the flow dribbles away to nothing. Property developers, anxious to take advantage of a booming economy and a growing middle class, drill boreholes, but these now have to go deeper and deeper to reach water.

As for the Yamuna river, long the main source of the city's drinking water, it is clinically dead. Quantities of sewage are poured into it daily, 95% of which is untreated, and it is also a depository for industrial effluents, chemicals from farm runoffs and arsenic and fluoride contamination. The city's master plan proposes three new dams, but they will not be finished for several years.

Many other cities have problems like Delhi's, though mostly in less extreme forms. Nearly two-fifths of the United States' 25,000 sewer systems illegally discharged raw sewage or other nasty stuff into rivers or lakes in 2007-09, and over 40% of the country's waters are considered dangerously polluted. Contaminated water lays low almost 20m Americans a year.

Pollution, however, is not the reason that people in rich countries have taken to drinking bottled water. In the developing ►►

▶ world they do it because that is often the only water fit to drink, and for the poor it is usually a significant expense. Not only are their incomes small, but they often pay a lot more for drinking water than do their richer compatriots. A litre of bottled water in India costs about 15 rupees (35 cents).

Bottled water often comes from the same source as tap water, where that is available (sometimes at a hundredth of the price), though it should at least be clean. It is often indistinguishable from tap water. In rich countries, it may have come from exotic sources like Fiji or Lapland, packed in glass or plastic destined to become rubbish, devouring energy on its travels and thus making it one of the least green and least defensible rip-offs on the market.

A concerted international effort is now under way to improve sanitation and the supply of drinking water. One of the development goals set by the United Nations at the millennium was to halve the proportion of people without basic sanitation and a decent source of fresh water by 2015. Progress is slow, especially for sanitation, and particularly in Africa, and increasingly policymakers are finding that heavily subsidised projects are failing.

### Sexy loos

Outfits like the World Toilet Organisation, based in Singapore, now believe you have to make lavatories “as sexy as mobile phones” if you are to get people to accept them, and that means literally selling them. Once people have invested some of their own money in a loo, they will use it. The World Bank confirms that the most successful sanitation projects involve only a small subsidy.

Where building a fixed latrine is not possible—slum-dwellers seldom own the



Not the place for a chat, though

land they live on, or have much incentive to improve a site to which they have no legal rights—entrepreneurs may help out. The Peepoo is a personal, single-use bag that the Swedish founder of the company, Anders Wilhelmsen, describes as the hygienic version of Nairobi’s flying toilet, intended, to begin with, for the same Kenyan users. Sealed by knotting, it acts as a micro treatment plant to break down the excreta. Since the bag is made of degradable bioplastic, when it has served its primary purpose it can be sold with its contents as fertiliser. Indeed, the hope is that a market will develop in which the same people will trade in the bags before and after use. Each will sell for 5-7 cents, about the same as a conventional plastic bag, and though a subsidy will be needed at first, the operation is meant to become self-sustaining, and indeed profitable.

Private enterprise also has a role in the provision of safe drinking water. A large market in home water-purifiers now exists all over the world. But a typical one, using reverse osmosis, may cost at least \$170 in a

country like India. Kevin McGovern, a self-described pro bono capitalist from New York, wants to bring cheaper purifiers to the poor. His company, the Water Initiative, has developed a filtering device that takes all the nasties out of water in the home and needs to be replaced only once a year. Unlike osmosis, it consumes no energy, and every drop of incoming water can be used for drinking.

The first country Mr McGovern has in his sights is Mexico, the second-biggest consumer of bottled water in the world because of the high incidence of arsenic, fluoride and pathogens in the water. Mr McGovern hopes to put in place a distribution system with a commercial interest in providing the machines and selling the filters. Volunteers and NGOs, he says, tend to set things up and then move on; a local commercial incentive is needed to sustain the operation, even if subsidies are required to get it started. Fortunately, two Mexican organisations have already promised grants, and the project is backed by the country’s popular first lady, Margarita Zavala. ■

## Business begins to stir

But many water providers still have a long way to go

**A**LTHOUGH water is a universal human requirement, the use people make of it varies hugely. The average Malian draws 4 cubic metres a year for domestic use, the average American 215. Include all uses, and the figures range from 20 cubic metres for the average Ugandan to over 5,000 for his Turkmenistani counterpart. The statistics can be misleading: in places where rain falls copiously and evenly from

the skies, withdrawals will be small. Moreover, water-blessed countries have much less reason to be careful with their resources than the water-starved. Yet high use of water is not necessarily bad. It depends how it is employed, and whether it is naturally replaced.

However essential, farming is not the most lucrative use of water. Industry generates about 70 times as much value from a

litre of water as agriculture, which helps to explain why industry takes the lion’s share in most rich countries. Yet the ratio of water use to GDP has declined dramatically in many rich and middle-income countries in recent decades, which suggests that industry can use water much more productively if it tries.

Unilever, a seller of soaps to soups in 170 countries, boasts that its Medusa pro- ▶▶

ject, formulated in Brazil in 2003, cut its total water use by 8% and reduced the load per tonne of production by 15%. SABMiller, which brews all over the world, has embarked on a programme to save a quarter of the water needed to make a litre of beer by 2015. Nestlé, which aims to be the most efficient water user among food manufacturers, has cut water withdrawals by a third since 2000 even though the volume of the foods and drinks it makes has risen by 60%. Cisco, which supplies internet routers, switches and the like, uses recycled water in its gardens and fountains in California and has installed waterless urinals and low-flow showers in its buildings.

Such measures make good financial sense and good public relations. Some of the companies at the forefront of water-saving campaigns are also acutely aware of their vulnerability to the growing scarcity of water, and to charges that they are guzzlers. Coca-Cola, for example, has been fiercely attacked in India for its dependence on groundwater and the effects on the water table. Yet even if it takes two litres of groundwater to produce a litre of bottled water, companies like Coca-Cola and PepsiCo are hardly significant users compared with farmers and even many industrial producers.

PepsiCo has nevertheless become the first big company to declare its support for the human right to water. For its part, Coca-Cola is one of a consortium of companies that in 2008 formed the 2030 Water Resources Group, which strives to deal with the issue of water scarcity. Last year it commissioned a consultancy, McKinsey, to produce a report on the economics of a range of solutions.

In China, where pollution rivals scarcity as a pressing problem, large foreign companies now regularly consult a website run by the Institute of Public and Environmental Affairs, an NGO that collects government facts and statistics and publishes them online. Its maps reveal details of thousands of incidents in which companies have broken the pollution codes. Multinationals like Adidas, General Electric, Nike and Wal-Mart can now see which of their suppliers are repeat offenders, and may put pressure on them to clean up.

Not all big companies are water-conscious, though, even if they are big users. A report issued this year by Ceres, a coalition of American investors, found that "the vast majority of leading companies in water-intensive industries have weak management and disclosure of water-related risks and opportunities." Less than half the elec-

tric-power companies surveyed even provided data on total water withdrawals.

Still, companies like Coca-Cola and Nestlé are being joined by others who are worried about being cast as villains. At the same time more and more companies are bringing forward new products and technologies designed to save water. These vary from genetically modified crop varieties that are drought-resistant to technologies that replace chemicals with eco-friendly enzymes in the making of knitwear; from low-lather detergents (which use less water) to dual-flush lavatories; from lasers that detect the amount of moisture in the air above crops to wireless devices that help reduce the water needed on golf courses (which account for 0.5% of America's annual water use, though some must help recharge aquifers).

Desalination is the great hope. The conventional method involves boiling and then distilling water. An alternative works by reverse osmosis, in which water is forced through a semi-permeable membrane. Both methods use quite a lot of energy. New membranes now being developed need less power, and new techniques require neither evaporation nor membranes nor futuristic nanotubes (undesirable in your drinking water).

Reverse osmosis is the most favoured method, though, and in Israel and Algeria contracts have been signed for salt-free water at about 55 cents a cubic metre. Even lower prices have been cited elsewhere,

but they do not usually reflect current energy costs or, increasingly, the non-energy costs of desalination. When it was mainly rich Gulf states and ocean liners that removed salt from sea water, ecological and financing concerns were generally overlooked. With desalination now favoured in places like Australia, California and Spain, those considerations have become more important. The city of Sydney, for instance, has had to install elaborate disposal systems for the briny waste of its desalination plant and use wind power in order to reduce CO<sub>2</sub>. All this is expensive.

### A no-briner?

Even so, several countries are going ahead, and Spain, the European Union's driest country, uses some desalinated seawater to irrigate high-value crops in its driest province, Almería. But its choice of desalination goes back to 2004, when it abandoned a hugely expensive and controversial scheme to divert water from the Ebro river in the north to the arid south. In general, people go for desalination when they have few other options and are able to bear the costs. That explains why both new capacity and investment in desalination plants have actually fallen since 2007, though Christopher Gasson of Global Water Intelligence expects them to rise this year. The hope is that, in the long run, solar power will make desalination economic.

In parts of Australia and America irrigation is becoming a sophisticated business in other ways. The gadgets involved may be computerised gates that control canal water, fancy flow meters or huge machines that sprinkle water sparingly from rotating pipes. And in time farmers and others everywhere should be able to take advantage of technology that measures evapotranspiration field by field.

This is already used by water-management agencies in the American West, thanks to a system developed by the Idaho state water department and the University of Idaho, which calculates the consumption of water from two Landsat satellites orbiting the Earth. Indeed, the use of sensors to take measurements from space is developing apace. The information they provide, perhaps conveyed straight to a farmer's mobile phone, should before long enable him to take intelligent decisions about how, when and where to grow his crops, even if he is scarcely literate.

His urban counterparts, and the utilities that serve them, may seem unimportant in terms of the amounts of water they use and lose. But domestic water supplies, ►►



With the compliments of Mr Neptune



## Every drop counts

And in Singapore every drop is counted

**N**O COUNTRY manages its water as well as Singapore. Admittedly, it has high rainfall and it is a tiny country, but that is exactly the trouble. As an island-city-state, it has little land on which to collect enough water for its 4.8m people, and not much room to store it. To supplement its bounty from above, it takes the salt out of sea water and imports supplies from Malaysia. But relations with its big neighbour are often strained; the two treaties under which the water is provided, both about 50 years old, will expire in 2011 and 2061 respectively; and Lee Kuan Yew, the father of the nation, has never forgotten that the invading Japanese blew up the water pipeline when they seized Singapore in 1942.

The first measure taken to escape foreign dependency in the years after independence in 1965 was a general tidy-up. Industry and commerce were shifted into estates and messy pig and duck farms closed down. That made it easier to purify the rainwater that in Singapore is fastidiously collected wherever it can be—in streets and ponds, even on tall buildings and bridges—before being taken by drains to reservoirs, and thence to treatment plants where it is cleaned to drinking-water standards. The catchment area is being increased by the creation of a pair of reservoirs, the first of which, due to be finished next year, will mean the rainfall-catchment acreage will extend to two-thirds of the island's total land area.

Little is wasted in Singapore. Used wa-

ter is treated and then either safely disposed of, reused for industrial purposes or air-conditioning, or mixed with reservoir water for drinking. Together, recycled waste and desalinated water are expected soon to meet 25-30% of demand, and local industries, many of them with a need for the cleanest supplies, are more than happy to use it. Most of the discarded sewage, once treated, is carried 5km out to sea.

Demand is also being contained. Subjected to constant water-consciousness

campaigns, Singaporeans are obliged to install low-use taps and loos, and expected to be equally thrifty with their showers and washing-machines. As a result, domestic water use per person has fallen from 165 litres a day in 2003 to 155 today. The pricing system also encourages virtue. Both the tariff and the water-conservation tax rise for domestic users after the first 40 cubic metres a month, and there is a fee for various sanitary appliances. Industry faces much higher charges.

How is all this achieved? The most important ingredient is a sense of seriousness about water at the highest levels of government and a society that is generally regarded as pretty free of corruption. Then comes an autonomous water authority, professionally run by excellent, highly paid professionals (the boss is said to receive \$700,000 a year). They are not afraid to bring in private-sector partners, and do what they believe needs doing, not what politicians want done. So money is invested in everything from dams and drains to membranes and bioreactors.

Singapore's water industry—over 50 companies, both local and foreign—is now thriving. Nanyang Technological University has three water-related units, and Singaporean companies are winning contracts in such countries as Qatar and Algeria. Singaporeans still import 40% of their needs. Even so, they have a supply of water that is clean, predictably delivered and reasonably secure. Sixty years ago they had floods, pollution and rationing.



Ready for drinking—over and over again

▶ though relatively small in volume, are expensive both to treat and to deliver. Water losses therefore matter, even if they help to replenish aquifers. And financial losses matter, too, because they discourage investment and encourage subsidies, which tend to benefit the better off, not the poor.

The utilities' reaction to water scarcity has been mixed. Many, including the World Bank, once believed that privatisation was the solution to the inefficient provision of water, but the new consensus, certainly in the bank, is that the crucial feature of any system is that it should be sensitive to its customers' needs. Thus, in Africa,

both Senegal and Uganda are judged to have well-run utilities, but Senegal's is private-sector whereas Uganda's is public. In general, Africa's utilities work better than, say, India's, largely because in Africa central governments are ready to give autonomy to professionals. In India water power lies with the states, often in huge, torpid, overstaffed and underfinanced bureaucracies. Vast quantities of water escape through leaking pipes; prices are unrelated to costs; meters are broken; and no effort is made to collect revenues. Accordingly, no money is available for repairs.

China has brought in private water

companies on a large scale, many of them foreign, and they have prospered there. In other places they have not always been a success. Some have suffered because the incoming company has accepted responsibility for the utility's foreign-currency debt, and then suffered exchange-rate losses that it had little choice but to pass on to customers. This happened in Cochabamba, a Bolivian town riven by water riots in 2000. It also happened to a company that took on one of two concessions in Manila, which duly foundered. The company that won the other concession, however, was largely free of exchange-rate liabilities ▶▶

▶ and has proved expansively successful.

Often the provision of water ranks too low among politicians' interests to make them do much. They would rather keep charges low or, in some places, non-existent than spend money on new pipes or treatment plants. They also see no votes in cutting the ribbon outside a new public lavatory. The result is that many utilities, especially in India, have spent so little on maintenance and new investment that the provision of water is, *faute de mieux*, priva-

tised. Thus the better off sink wells or fill their cisterns with deliveries from tankers, and the poor drink water bought in bottles and wash with whatever they can find.

Luckily, there are exceptions in places like Brazil, where simple sewers built cheaply in some *favelas* are proving highly effective. Entrepreneurs are also coming into the market with low-tech products. In Tanzania, masons will provide a concrete slab to install above a pit latrine for \$5. In Cambodia \$30 should buy you a flush lav-

atory of sorts; and in Indonesia a range of sanitary fixtures sell for \$18-90, and may even come with a warranty.

To get service from bad utilities, though, it is sometimes necessary to shame them. One way of doing this is to publicise their position in the rankings of the International Benchmarking Network for Water and Sanitation, published online. This is now causing several city governments some embarrassment—and at the same time giving hope to their ill-served customers. ■

## Making farmers matter

And monitor, budget, manage—and prosper

**O**F ALL the activities that need water, far and away the thirstiest is farming. Cut the use of irrigation water by 10%, it is said, and you would save more than is lost in evaporation by all other consumers. Yet farming is crucial. Not only does it provide the food that all mankind requires, but it is also a great engine of economic growth for the three-quarters of the world's poor who live in the countryside. Without water they may return to pastoralism—as some people already have in parts of the Sahel in Africa—or migrate, or starve. With water, they may fight their way out of poverty.

Surface water, though, is not enough to meet farmers' needs. In the United States total withdrawals of water remained steady between 1985 and 2000 but groundwater withdrawals rose by 14%, mainly for agriculture, and in the period 1950-2000 they more than doubled. This was not all for the arid West. Midwestern Nebraska now ranks above California and Texas as America's most irrigated state. Europe, too, increasingly relies on groundwater, as does the Middle East. In a network of pipes that Colonel Muammar Qaddafi has called the eighth wonder of the world, Libya is drawing fossil water that has lain undisturbed for centuries. Many hydrologists think it will be all but exhausted in 40 years.

It is India, though, that draws more groundwater than any other country. The 230 cubic kilometres that it pumps each year account for over a quarter of the world total. The tripling of Indian groundwater use since 1965 has been stimulated not just by growing demand for food but also by the lamentable public service provided by state governments and the relative cheapness and convenience of a priv-

ate tubewell. By 2001 India had about 17m of these (and Pakistan 930,000 and Bangladesh 1.2m). The pumps for the wells are usually cheap to run because electricity is subsidised in most places, and in some it is free, though at times it is not provided at all; that is how water is rationed.

The proliferation has brought prosperity and an almost lush landscape to places like Punjab, which grows over half of India's rice and wheat. But out of sight, underground, there is trouble. Water is being extracted faster than it is replaced and levels are falling, often by two or three times the officially reported rate, according to Upmanu Lall, of Columbia University. The World Bank says the groundwater in 75% of the blocks into which Punjab is divided is overdrawn. Over half the blocks of five other states—Gujarat, Haryana, Maharashtra, Rajasthan and Tamil Nadu—are judged to be in a critical or semi-critical condition, or are similarly over-exploited.

### Up comes the poison

One consequence is that the water now being pumped is often salty and sometimes high in concentrations of naturally occurring poisons like arsenic, fluorides and uranium. In the village of Bhutal Kalan in Sangrur district, for instance, the farmers complain not just of water levels dropping by two metres after each of the two harvests a year but also of fluorosis, which may cause mottling of the teeth and skin, or, in its skeletal form, arthritic pain and bone deformities. Cancer is also rising, which the farmers blame on the natural poisons and on pesticides, which they apply specially heavily if they grow cotton.

The farmers' woes do not end there.

Though part of the Sangrur district suffers from a falling water table, the other part suffers from waterlogging. This is a common problem when poorly drained soil is over-irrigated, which results in plants' roots being starved of oxygen, knocking perhaps 20% off a field's productivity. Sometimes standing water will evaporate, leaving the soil salty as well as saturated.

Tushaar Shah, in "Taming the Anarchy", his book on water in South Asia, says the groundwater irrigation boom in India is "silently reconfiguring" entire river basins. But of more immediate concern to the farmers are the economic and social consequences of overdrawing groundwater: falling yields, higher electricity costs, ever greater debts, even rising crime among the unemployed. Increasingly, say the farmers, they must look to other, part-time jobs, like driving a taxi. Or they must sell their land. Usually it will go to a village bigwig, perhaps with a little help from local officials.

The main winners, though, are the *arhtiyas*, the commission agents who act as middlemen between farmers and wholesale buyers and at the same time moonlight, sometimes extortionately, as moneylenders. Few farmers, big or small, are free of debt, and worries about interest payments have driven thousands of Indian farmers to suicide in recent years, many more than the official figures suggest, says Chander Parkash, an academic who helps to run a local NGO for farmers.

Back in Delhi, Himanshu Thakkar, of the South Asia Network on Dams, Rivers and People, casts a more dispassionate eye over the Indian water scene. In Punjab he discerns a state hooked on irrigation. Reluctant to share its river waters with other ▶▶

states, it has passed laws to cancel earlier inter-state agreements. Its depletion of the aquifer also robs its neighbours in the Indus basin. Yet Punjab's farmers benefit from (state or central) government spending on dams and canals; on help with inputs such as new seeds and fertilisers; on the security of a guaranteed support price for their produce; and on subsidies for electricity (which is in effect free). Lastly, in Punjab at least, the water pumped is not even metered, let alone paid for.

Down in the south-east, Andhra Pradesh also sees its groundwater disappearing. But unlike Punjab, whose alluvial aquifers in equilibrium are recharged by monsoonal rain and leakage from irrigation canals, Andhra Pradesh relies entirely on the monsoon for its groundwater replenishment. Moreover, since it sits on hard rock, only about 12% of the annual rainfall goes to recharge the aquifers, compared with perhaps 30% in Punjab, and subterranean water tends to run away into rivers after a month or two, so underground storage is limited.

Out in the arid west of the state, drought is almost the normal condition and, for the first time in India, a large number of farmers are starting to deal with it by reducing their demand rather than by pumping more and more from deeper and deeper. The idea behind a project that now involves nearly 1m people in 650 villages is to monitor, demystify and thus manage groundwater. The nine NGOs that run the scheme offer no subsidies, just knowledge.

At Mutyalapadu and round about, this comes from the Rev V. Paul Raja Rao's Bharati Integrated Rural Development Society,



Hydrological budgeting in Andhra Pradesh

which also runs a clinic, an orphanage and a microcredit organisation. One of the first water-management tasks for an organisation such as this is to map the locality and define its hydrological units, each of which is an area drained by a single stream with one inlet and one outlet. The region encompasses 11 hydrological units, one containing 41 villages. Some are much smaller.

The farmers taking part in the project measure and record rainfall, the water table, withdrawals and other data for their land. They calculate how much water will be available if the table is not to fall, decide which crops to grow and estimate how much water they will use, bearing in mind that about half will go in evapotranspiration. They then sit down together in a group—there are several of these for each hydrological unit—and draw up a water budget. Details of the eventual agreement, showing who should grow what and how,

are displayed on a wall in the village and updated over the year with information about rain, harvests and even revenues.

No one is compelled to take part; the enterprise is voluntary and collaborative. But so far most farmers, and their families, seem pleased. The local diet has become more varied, since 13 crops are now grown in the area, compared with eight in the past. Those that need most water—bananas, rice and cotton—have yielded to others that need less, such as peanuts and a locally bred variety of green lentils. Chemical fertilisers have been replaced by compost, a change welcomed for both health and financial reasons. Mulch, manure and organic weedkillers are also used. The upshot is that although incomes have not risen—most of the crop is eaten, not sold for cash—the cost of inputs has fallen and those involved feel they are engaged in a sustainable activity.

That is because the scheme puts the people who invest the money, grow the crops and live or die by their efforts in charge of their most crucial resource; they are all barefoot hydrogeologists. The relentless drilling of wells has abated: in two units near Mutyalapadu no new wells were bored over two recent seasons, and in the wider region only eight out of 58 units showed no reduction in pumping. Overdrawing is judged to be under control, partly because everyone knows what is happening. And the idea is catching on. The entire water department of Andhra Pradesh has been trained in the basic principles; Maharashtra has three similar projects under way; and Gujarat, Orissa and Tamil Nadu are keen to follow suit. ■

## China's peasants look to the skies

But the science of yields is unyielding

IF THE Andhra Pradesh principles point the way to a reasonably equitable future, they will have to be adopted not only throughout South Asia but also in China, where the water available to each person is only a quarter of the world average. In the rain-starved north, the availability per person is only a quarter of that in the south. Yet this is where almost half China's population lives, and where most of its maize, wheat and vegetables are grown.

Water scarcity is hardly new in China, whose irrigation records go back 4,000

years, but the use of groundwater is. In the 1950s this was virtually unknown in the north. Today there are more wells there than anywhere else in the world, and they are relentlessly pumped, with alarming results. For instance, in the Hai river basin, in which both Beijing and Tianjin lie, shallow water tables have dropped by up to 50 metres, deep ones by up to 90. These will not quickly be put right.

Chinese governments have usually responded to shortages with canals, dykes, storage ponds and so on. The 1,800km

Grand Canal, started in 486BC, was built chiefly to move grain to the capital, but will now become part of the great South-North Water-Transfer Project, intended to slake the thirst of China's arid regions. Dams and canals appeal to the engineers who are disproportionately represented in China's government. And the country's engineers are still taught that the way to "save" water is to improve the way it is delivered—by lining irrigation canals, for instance, or laying pipes—to reduce the water that is "lost" by seeping into the soil. ►►



Another mineshaft

▶ In truth, though, such water is not all lost: much of it returns to the aquifers below, from where it can be pumped up again. There is a cost to this, in energy and therefore cash, but not in water. The only water truly lost in a hydrologic system is through evapotranspiration, since no one can make further use of it once it is in the atmosphere. If genuine savings are to be made, either evaporation must be cut (for example, by storing water underground, or by delivering it to plants' roots under the surface of the soil); or food must be produced with less transpiration.

### The trouble with efficiency savings

Almost all China's (and others') attempts at using groundwater more efficiently so far have foundered on a failure to grasp these facts. The water "saved" by sprinklers, lined canals and other forms of seepage control has simply been used to expand the area under irrigation. Over the past 30 years this has gone up by 8m hect-

ares, allowing food production to increase even though the amount of pumped water has remained much the same. But ET has risen, so aquifer depletion has continued.

Sometimes, say Frank Ward, of New Mexico State University, and Manuel Pulido-Velázquez, of the Technical University of Valencia, policies aimed at reducing water use can actually increase groundwater depletion. This has happened in the Upper Rio Grande basin shared by the United States and Mexico, where measures designed to achieve more efficient irrigation have led to an increase in yields upstream; this in turn has increased ET, leaving less water available for aquifer recharge.

Such discoveries increase the attractiveness of demand management, and that is being tried in China as well as in Andhra Pradesh. In a project that covers several parts of arid and semi-arid China—Beijing, Hebei, Qingdao and Shenyang, as well as the Hai basin and the smaller Turpan basin—the World Bank has been promoting

water conservation. Elements of the approach are similar to that in Andhra Pradesh: farmers gather in water-users' associations to plan and operate irrigation services, for example. But the aim here is specifically to reduce ET, at the same time increasing farmers' incomes without depleting the groundwater.

This is high-tech stuff that involves not just drip irrigation and condensation-trapping greenhouses, but remote sensing by satellites which provide ET readings for areas of 30 by 30 metres. This tells farmers how much water they can consume without adversely affecting the ecosystems in their river basin. If the project is successful, as a pilot has been, it will also establish the use of an internet-based management system, mitigate losses from flooding and increase the supply of water to industry.

If such practices were extended across Asia, groundwater depletions might well be arrested. With luck, farmers too would be better off. But would they produce enough food for the extra 2.5 billion people expected by 2050 in today's developing countries? The constraints seem to be set by science, and they are tight.

Growing more crops over a wider area leads to more ET. The yield of a crop can be increased a bit by giving plants only as much water as they need and no more; but, says Dr Perry, the water accountant, the productivity gains are unlikely to exceed 10%. Increases in biomass—total vegetative matter—are matched almost proportionately by increases in transpiration, unless humidity or nutrients are changed or the plant is modified genetically. But so far, he notes, "the fundamental relationship between biomass and transpiration has not been changed." ■

## The ups and downs of dams

Small projects often give better returns

THE trouble with water is that it is all politics, no economics. The costs of poor management are large: groundwater depletion takes 2.1% off Jordan's GDP; water pollution and scarcity knock 2.3% off China's; 11% of Kenya's was lost to flooding in 1997-98, and 16% to drought in the next two years. Rich countries build sewers, drains, dams, reservoirs, flood defences, irrigation canals and barrages to avoid such problems. Poor countries, with some ex-

ceptions, notably China, find large projects much more difficult. But at least large projects give politicians a monument to boast about. Small projects—weirs and wells and waterworks—have no allure for big-headed politicians.

That is a pity. A small dam is relatively cheap to construct: modest reservoirs known in India as tanks used to be built and maintained by local villagers. For a millennium they provided water in times

of need and helped make rulers like the nizams of Hyderabad some of the richest men in the world. Now they are often silted up, polluted with pesticides, metals and phosphorus, or built on. In Kenya, by contrast, small dams are coming into fashion. Rainwater is channelled into sand catchments, which serve both to filter it and to protect it from evaporation. Some goes into nearby soil, for crops, some into groundwater from which it can later be re-▶▶



**The politician's delight**

► covered. In Niger a 15-year project involving dams and reclamation has restored nearly 20,000 hectares of unproductive land to forestry or agricultural use.

Everyone loves projects like these, especially if they can be given a romantic name like water harvesting. Some, perhaps, may simply be intercepting water for one user that would otherwise have gone to another, but almost every country could reduce its evaporation losses by capturing water and delivering it more effectively to the farmer, bather, drinker or manufacturer—and then, ideally, using it again. The harder question is whether that is enough.

Many believe it is not. Throughout history, man has made efforts to control water, divert it by means of canals, carry it via aqueducts, store it in reservoirs, harness it with water wheels and so on. The costs of these endeavours have been huge: valleys flooded, villages and habitats destroyed, wetlands drained and inland seas reduced to mere puddles. But the benefits have also been enormous.

The Aswan high dam, for example, is often cited as a cautionary example, a quixotic construction that now reduces the mighty Nile to a dribble before it trickles to the sea, leaving behind an explosion of water hyacinth, outbreaks of bilharzia, polluted irrigation channels and a build-up of sediment inland that would otherwise compensate for coastal erosion from Egypt to Lebanon. Yet, according to the World Bank, it has provided a bulwark against flooding for buildings and crops, a huge expansion of farming and Nile navigation (lots of tourism) and enough electricity for the whole of Egypt—all of which amounts to the equivalent each year of 2% of GDP in net benefits.

So would the World Bank today lend money for an Aswan dam if it did not already exist? The bank has been involved in

few of the 200 or so large dams built in the past five years, but that is mainly because dam-builders—of which China is much the biggest—do not care for the bank's time- and money-consuming regulations, designed to ensure decent technical, social and environmental standards. Their strictness partly reflects greater knowledge about the consequences of building dams, partly the related political controversies of the 1980s. Even so, the bank was involved in 101 dam and hydro projects in 2007, up from 89 in 1997 and 76 in 2003; and it approved over \$800m in hydro lending in 2008, up from \$250m in 2002.

Suspensions of big dams still run high—and with some reason. Mr Thakkar, scrutineer of the Indian water scene, says that although the installed capacity of India's hydro projects increased at a compound rate of 4.4% a year between 1991 and 2005, the amount of energy generated actually fell. Some of the projects, poorly sited or poorly designed, were doomed to be uneconomic from the start. Others have been badly maintained or have simply silted up. But though 89% of the country's hydro projects operate below design capacity, the building continues wastefully apace.

Mr Thakkar argues that small projects offer much better returns, even for the crucial task of refilling aquifers by capturing monsoon rainfall. He points to the success of micro-irrigation in semi-arid Gujarat, whose agriculture has grown at an average of 9.6% a year since the turn of the century, partly thanks to the creation of 500,000

small ponds, dams and suchlike. But India, says Mr Thakkar, is still obsessed with big projects like the Bhakhra dam that the country's first prime minister, Jawaharlal Nehru, saw as one of the "temples" of Indian modernity. Only when the small temples can no longer provide solutions does he see a need for big ones.

Not all the big temples are dams. India has a dormant but not dead \$120 billion scheme to bring "surplus" water from north to south by linking up the country's main rivers. China has its south-north equivalent, which, if it comes to pass, may involve spending \$62 billion and shifting 250,000 people. Spain had its Ebro scheme, involving 830km of waterways, now abandoned, though some Spaniards remain wistful. Each of these has, or had, beguiling attractions, but vast costs.

### **Big can also be beautiful**

Dams and reservoirs certainly need constant repairs and careful maintenance and do not always get them, usually because the necessary institutions are not in place. But when they are, a well-sited dam or embankment can transform lives for the better. In the late 1970s John Briscoe, an old water hand at the World Bank who is now at Harvard, spent a year in a Bangladeshi village and predicted terrible consequences if a proposed flood-control and irrigation scheme were to go ahead. It did, but on his return 22 years later he found the new embankment had vastly improved every aspect of the villagers' lives. He be- ►►



**Overdammed Colorado**

► came an advocate of large projects.

In the rich world these are now largely unnecessary; the damage has been done and the benefits are being reaped. Southern California is an example, a region that gets all its water expensively from either the north of the state or the Colorado, a river so dammed and drained that it dies long before it reaches its delta—7,500 square kilometres of wetlands formerly crammed with wildlife, now invaded by the salty Pacific. But Hollywood survives, and in it such environmentalists as James Cameron, the director of “Avatar” and new champion of the Amazonian opponents of the planned Belo Monte dam in Brazil.

Many Ethiopians would be happy to have a few dams. Their GDP rises and falls

in near synchrony with their rainfall, which varies wildly from year to year. If they had more storage, they could use it to get through the country’s frequent droughts, but their man-made storage amounts to only 30 cubic metres per person, compared with 6,000 in the United States. Ethiopia’s electricity consumption per person is among the lowest in the world, whereas its potential for hydro power is one of the highest. Indeed, electricity could be a valuable export.

Africa as a whole stands to benefit from more hydro projects, large and small. Climate change seems likely to shorten the rainy seasons and intensify variability, making storage even more important. Moreover, Africa seems likely to suffer

more from climate change than other continents. As it is, it contains 35 of the 45 most “water-stressed” countries.

Hydro generation uses a known and tested technology that neither adds directly to greenhouse gases nor produces nuclear waste. Last month the World Bank announced a controversial \$3.75 billion loan for a coal-fired plant in South Africa. Some hydro projects might be no more unpopular. Congo’s Inga dams, for example, have the potential to provide the equivalent of South Africa’s existing capacity. The South African authorities would be pleased to have it today. Their fingers are crossed that the hydro power from Mozambique will not cut out during the football World Cup next month. ■

## Trade and conserve

How to make tight supplies go further

**I**F MOST governments are bad at making wise investment decisions about water, that is largely because they are bad at evaluating the costs and benefits, and that in turn is at least partly because they find it hard to price water. Many find it hard even to measure. Yet you cannot manage what you cannot measure.

No country uses water pricing to achieve a balance between supply and demand, but countries with sustainable systems all use water rights of some kind that involve the allocation of supply by volume. In a country such as India, which has over 20m well-users, even the registration of wells would be a long and difficult task, as the World Bank points out, never mind measuring the water drawn from each of them. Moreover, introducing a system in which price reflected some sort of cost would often be politically impossible except over time.

Dr Perry, the irrigation economist, says water is typically priced at 10-50% of the costs of operating and maintaining the system, and that in turn is only 10-50% of what water is worth in terms of agricultural productivity. So to bring supply and demand into equilibrium the price would have to rise by 4-100 times. In most countries that would spell electoral suicide, or revolution. That is why community management of the Andhra Pradesh or Chinese kind, which may involve a mix of instruments including regulation, property rights and

pricing, offers the best hope.

In the long run it is hard to see sustainable arrangements that do not involve property rights. These can be traded between willing buyers and willing sellers to reallocate water from low-value to high-value uses, and they have proved their worth in the American West, Chile and South Africa. Their most fashionable exemplar is the Murray-Darling basin in Australia, where they have enabled farmers to withstand a fearsome drought without much impact on agricultural production.

Yet water rights do not provide an easy or quick fix to water shortages. For a start, they usually require tested institutions and the ability to ensure fair trading that may take years to establish. Then the scheme, and particularly the assignment of rights, must be carefully designed. Experience in Australia and Chile shows this can be difficult; indeed, the Organisation for Economic Co-operation and Development says there is now widespread recognition that the Murray-Darling system is over-allocated. Spain, which after 20 years has registered less than a quarter of its groundwater structures, shows that this can take a long time. And Yemen shows that trading in the absence of proper regulation can actually add to groundwater depletion, as has happened around the city of Ta’iz. Lastly, farmers may be resistant to tradable rights. Even Israel, hyper-conservation-conscious in water matters, still allocates

water centrally among different sectors, and controls use within sectors by permits and pricing. Rights provide quotas, but Israeli farmers do not want to see them traded—and the water table drops.

Above all, it is difficult to include small groundwater-users in a tradable-rights scheme. Nebraska neglects small users, as does Australia. But to do so in India would exclude 95% of the people pumping water. This reinforces the argument for collaborative self-policing of withdrawals by farmers themselves.

### Comparative advantage

Plainly, however, that is not going to happen fast, so other solutions are needed. One would be trade. Just as an efficient local trading system should direct water to high-value uses, so an efficient international one should encourage the manufacture of water-heavy products in wet countries and their export to drier ones.

It is not, of course, instantly obvious that some products are lighter or heavier than others in terms of the water embedded in them, yet the amount of this “virtual” water can be calculated and a water “footprint” sketched for almost any product, person, industry or country.

On the back of the business card handed out by Tony Allan, the father of the concept, are the virtual-water values of various products: 70 litres for an apple, 1,000 for a litre of milk, 11,000 for a kilo of cotton, ►►

▶ and so on. The value for a copy of *The Economist* is not included, but it has been calculated by the Green Press Initiative at about 11½ litres. That is little more than the 10 litres Mr Allan has for a single sheet of A4 paper, which suggests the exercise is inexact.

It can also be misleading. The oft-quoted figures of 2,400 litres for a hamburger and 15,500 for a kilo of beef lead to the conclusion that eating cows must be unconscionable. Yet some cows valued primarily for their milk may still end up on a plate, and others may be well suited to graze on grassland that would be useless for growing cash crops. In Africa a kilo of beef can be produced with as little as 146 litres of water. Moreover, virtual-water content will vary according to climate and agricultural practice. SABMiller uses 45 litres of water to make a litre of beer in the Czech Republic, but 155 litres in South Africa. In other words, the merit of virtual water is not to give precise figures but to alert people that they might be better off growing different crops, or moving their manufacturing to another country.

Or trading. If the virtual water in traded goods were properly valued and priced, exporters would be fully compensated



The price is not right

and importers would pay a price that reflected all the costs. But water is everywhere hugely subsidised, and protectionism often stops an efficient allocation of resources. State laws in America, for instance, usually restrict foreign investment in agricultural land. The upshot, at its most absurd, has been Saudi Arabia's decision to use its finite fossil fuel and fossil water to irrigate the desert for wheat that could be grown with less energy and less evapo-

transpiration in the American Midwest and then exported to the Middle East.

Unfortunately, Henry Kissinger once raised the thought that America might use its food aid as a weapon. More recently, when food prices shot up in 2008, some countries started to impose export bans or taxes, leading importers to hanker for self-sufficiency. Virtual water seems destined to remain an indicator of distorted allocation for some time to come. ■

## To the last drop

### How to avoid water wars

SINCE men fight over land and oil and plenty of other things, it would be odd if they did not also fight over a commodity as precious and scarce as water. And they do. The Pacific Institute in California has drawn up a list of conflicts in which water has played a part. It starts with a legendary, Noah-and-the-flood-like episode about 3000BC in which the Sumerian god Ea punished the Earth with a storm, and ends, 202 incidents later, with clashes in Mumbai prompted by water rationing last year. Pundits delight in predicting the outbreak of water wars, and certainly water has sometimes been involved in military rows. But so far there have been no true water wars.

Could that change as populations grow, climates change and water becomes ever scarcer? Since 61 of the 203 incidents have taken place in the past ten years, a trend might seem to be in the making—especially as some recent water disputes fail to make the list even though their results look

grave. One example is the competition for water in Bharatpur, a district of the Indian state of Rajasthan, which has led local farmers to cut off water supplies to the Keoladeo national park. This was, until a few years ago, a wonderful wetland, teeming with waders and wildfowl. Thousands of rare birds would winter there, endangered Siberian cranes among them. Now it is a cattle pasture.

China abounds with instances of water-induced disputation. The people of Hebei province, which surrounds Beijing, are far from happy that their water is now taken to supply the capital in a canal that will eventually form part of the South-North Water-Transfer Project. So are others affected by that grandiose scheme. Dai Qing, an investigative journalist who is an outspoken critic of the Three Gorges dam and other Chinese water projects, draws attention, for example, to the complaints of those living along the Han river, who will lose water to the huge reservoir formed by the

Danjiangkou dam.

Similar disgruntlement can be seen in India, where over 40 tribunals and other panels have been set up to deal with disputes, mostly without success. The bone of contention is often a river, such as the Cauvery, whose waters must be shared by several states. Strikes and violent protests are common. Indians, however, have yet to reach the levels of outrage that led Arizona to call out its National Guard in 1935 and station militia units on its border with California in protest at diversions from the Colorado river. To this day, American states regard each other with suspicion where water is concerned. Indian states are equally mistrustful, often refusing to share such water information as they have lest it be used to their disadvantage.

Violent incidents over wells and springs take place periodically in Yemen, and the long-running civil war in Darfur is at least partly attributable to the chronic scarcity of water in western Sudan. That is ▶▶

▶ probably the nearest thing to a real water war being fought today, and may perhaps be a portent of others to come. If so, they will be dangerous, because so many water disagreements are not internal but international affairs.

### Arid disputes

The world has already had a taste of some. The six-day war in the Middle East in 1967, for example, was partly prompted by Jordan's proposal to divert the Jordan river, and water remains a divisive issue between Israel and its neighbours to this day. Israel extracts about 65% of the upper Jordan, leaving the occupied West Bank dependent on a brackish trickle and a mountain aquifer, access to which Israel also controls. In 2004 the average Israeli had a daily allowance of 290 litres of domestic water, the average Palestinian 70.

Turkey's South-Eastern Anatolia Project, intended to double the country's irrigated farmland, involves the building of a series of dams on the Tigris and Euphrates rivers; one of them, the Ataturk dam, finished in 1990, ranks among the biggest in the world. Iraq and Syria downstream are dismayed. Similarly, Uzbekistan views with alarm Tajikistan's plan to go ahead with an old Soviet project to build a huge barrage across the River Vakhsh. This, the Rogun dam, will be the highest in the world, at least for a while, and was expected in 2008 to cost about \$2.2 billion, or 43% of the country's national income. The dam will, it is hoped, generate enough power for all Tajikistan's needs and have plenty over to export as far afield as Afghanistan and Pakistan. But since it may take 18 years to fill the dam (compared with 18 days, in principle, for China's Three Gorges), there may be no water left over, or at any rate not enough for Uzbekistan's cotton-growers.

International river basins extend across the borders of 145 countries, and some rivers flow through several countries. The Congo, Niger, Nile, Rhine and Zambezi are each shared among 9-11 countries, the Danube among 19. Adding to the complications is the fact that some countries, especially in Africa, rely on several rivers; 22, for instance, rise in Guinea. And about 280 aquifers also cross borders. Yet a multiplicity of countries, though it makes river management complicated, does not necessarily add to the intractability of a dispute.

One arrangement now under strain is the 1960 Indus Waters Treaty between India and Pakistan. This agreement was the basis for the division of rivers after India's partition in 1947. Having withstood Indo-

Pakistani wars in 1965, 1971 and 1999, it is usually cited as a notable example of durability in adversity, but it is now threatened by three developments.

First, India proposes to build a water-diversion scheme in Indian Kashmir that would take water from the Kishanganga river to the Jhelum river before it could reach Pakistani Kashmir. Second, India, which already has more than 20 hydro projects on the three western rivers allocated to Pakistan in its part of Kashmir, is now building at least another ten and has more planned. Each of these conforms to the letter of the treaty, since it does not involve storage but merely run-of-the-river dams, in which water is returned downstream after it has been used to generate power. However, Pakistan is worried about the cumulative effects. When, in 2005, it complained about another Indian hydro project, the dispute went to arbitration. That resulted in a ruling broadly favourable to India which left Pakistan unhappy. It feels that the spirit of the agreement has been breached and the treaty needs revision, partly because advances in technology

make it possible to build dams that were not foreseen when the deal was signed.

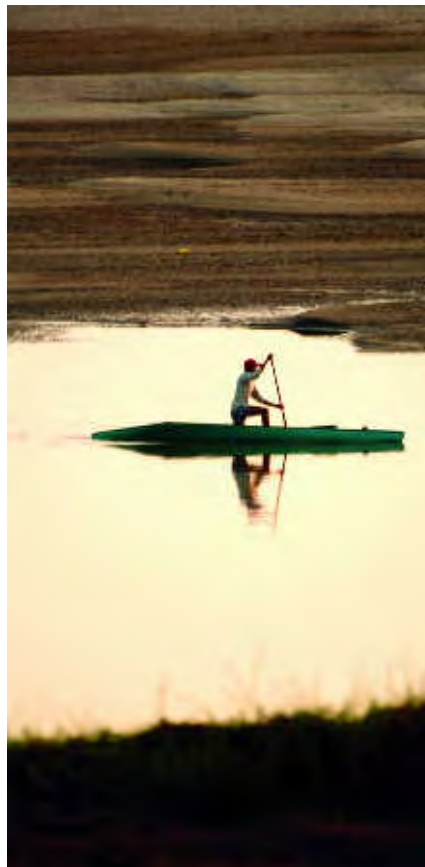
Third, Pakistan badly needs more reservoirs. Storage is essential to provide supplies in winter (two-fifths of the Indus's flow comes from the summer melting of glaciers) but Pakistan's two big dams are silting up. It would like to build a new one in Pakistani Kashmir, but India has objected, and the money is not forthcoming.

Another example, the Nile, looks more worrying but is perhaps more hopeful. The Blue Nile rises in Lake Tana in the Ethiopian highlands, the White Nile in Lake Victoria in Uganda (into which flow rivers from Rwanda and Tanzania). The two Niles meet in Sudan and flow through Egypt, which gets almost no water from anywhere else. For years most of the territories that now form the riparian countries were under the direct or indirect control of Britain, which was fixated on Egypt. Britain stopped any development upstream that would reduce the flow of water to Egypt and, in 1929, allotted 96% of the water flowing north from Sudan to the Egyptians and only 4% to the Sudanese.

Thirty years later Gamal Abdel Nasser had to make a new treaty with Sudan in order to build the Aswan high dam. It would have made more sense to build a dam in the Ethiopian mountains: not only would the flow have then been easier to control but it would also have been cheaper and environmentally less damaging—and with less evaporation. But demagogues like their own dams. The waters were split 75% to Egypt and 25% to Sudan.

The other riparian states have been unhappy ever since, Kenya and Ethiopia particularly so, and all efforts to draw up a new treaty, fairer to all, have failed. They have not, however, failed to achieve anything. On the contrary, for the past 11 years the ten riparians have been amicably meeting in an organisation called the Nile Basin Initiative, and since 2001 have had a secretariat that deals with technical matters and holds ministerial gatherings.

In this group, irrigation and other projects are agreed on, many with World Bank support. Ethiopia is building three dams, two of them large and one controversial, for environmental reasons; and Egypt will take some of the electricity generated, via Sudan. In this way will two old antagonists yoke themselves together with water, the very commodity that has so long driven them apart. No one would say that a new agreement among all the interested parties is imminent, but, after more than 100 trips to Egypt and Ethiopia to help promote har- ▶▶



Too quiet flows the Mekong



mony, Mr Grey, World Banker turned Oxford professor, is hopeful. He believes that, in time, Ethiopia could be an exporter of electricity to Europe.

A third neuralgic dispute concerns the Mekong, one of at least eight rivers that rise on the Tibetan plateau, fed partly by melting glaciers in Tibet. The Mekong then runs through China's Yunnan province, Myanmar, Laos, Thailand, Cambodia and Vietnam. Recently, though, it has been running thinly. Sandbanks have appeared, navigation has slowed, fishermen complain of derisory catches, and the 60m people whose livelihoods directly or indirectly depend on the river are worried. The worst drought in southern China for 50 years is partly, perhaps mainly, to blame, but the downstream users also blame the Chinese government, and in particular the three dams it has built and its blasting of rapids to ease navigation.

China has plans for more dams. It is hyperactive in the world of water, not only at home but abroad—building dams in Africa and Pakistan, looking for land in Mozambique and the Philippines, diverting rivers for its own purposes. Neighbouring states, notably India, are uneasy. Yet the row over

the drop in the Mekong seems under control. At a meeting of the Mekong River Commission last month—all the riparian states except China and Myanmar are members—China sent a vice-minister of foreign affairs, who was fairly forthcoming about hydrological data. This was something of a breakthrough, even if he did not offer compensation to fishermen. The neighbours' resentment has not disappeared, and China will not stop building dams. But a water war seems unlikely.

The most hopeful development is the success of other river-basin organisations like the Nile and the Mekong groups. Such outfits now exist for various rivers, including the Danube, the Niger, the Okavango, the Red, the Sava and so on. In the Senegal river group, Mali, Senegal, Guinea and Mauritania have agreed to disagree about who is entitled to how much water, and instead concentrate on sharing out various projects, so that a dam may go to one but the electricity generated, or a part of it, to another. This has worked so well that the president of the group has established considerable authority, enough to enable him to broker unrelated agreements among squabbling tribesmen.

The co-operative approach has also been successful elsewhere. Thailand, for instance, has helped pay for a hydro scheme in Laos in return for power; South Africa has done the same with Lesotho, in return for drinking water in its industrial province of Gauteng; and, in the Syr Darya grouping, Uzbekistan and Kazakhstan compensate Kyrgyzstan in return for supplies of excess power.

The way such organisations work, when they work, is to look for the benefits that can be gained from organising water better, and then to share them. An arrangement can usually, though not always, be found that benefits each state. It may be hard to achieve in a group that includes a dominant member, such as Egypt. And it will also be more difficult in groups that bring together officials appointed politically rather than competitively, on their technical qualifications. In the case of the Indus the two sides' representatives get along well. The reason the treaty is under strain is that it starts with the water and then tries to divide it equitably. The secret is to look for benefits and then try to share them. If that is done, water can bring competitors together. ■

## A glass half empty

It won't fill up without lots of changes on the ground—and much greater restraint by users

**C**AN the world solve its water problems? There is no reason in logic, physics or hydrogeology why it should not be able to do so. Most of the obstacles are political, although some are cultural, and none is helped by water's astonishing ability to repel or defy economic analysis.

Many of the small solutions are known. Some involve physical remedies. Flood protection demands embankments, or dams, or protected flood plains, or houses that rise and fall with the waters. Short rainy seasons demand water storage, ideally in places where evaporation is low. Human health demands clean water, and perhaps mosquito nets, and soap. Flourishing ecosystems require pollution control. And so on.

Some of the remedies require changes in behaviour, and policies to bring them about. If people are to use water with more care, they must know how much they draw and what it costs. They must also know how to use it, and reuse it, produc-

tively. To make progress on this front requires education, not least of politicians. Then policies must be drawn up and implemented. All this requires money—for meters, pipes, sewers, satellites, irrigation, low-flow taps and umpteen other things.

Some policies apparently unconnected to water must change too. Trade and investment must be unfettered if water-short countries are to be encouraged to import water-heavy goods and services, rather than relying on their own production. Using crops like sugarbeet to make bio-fuels in dry regions must be abandoned. Governments must overcome their love of secrecy and reveal all the information they have about river flows, water tables, weather forecasts, likely floods. They must also look to non-water policies to solve water problems. For example, building a road passable in all weather all year round to let farmers get their produce to market will enable them to move from subsistence to commercial agriculture.

For their part, smallholders in many places will have to reconcile themselves to selling their land to allow the creation of larger, more efficient farms. Some farmers must grow more high-value, not-too-thirsty crops like nuts or strawberries or blueberries. And consumers will have to accept genetically modified varieties.

Personal habits, too, will have to change. Meat-eaters may have to hold back on hamburgers and learn to love soya. Golfers may have to take up basketball. The horizontally mobile may have to stop washing their cars. And everyone will have to become accustomed to paying more for food. At present the only water costs usually passed on to consumers concern transport or treatment. The scarcity of water is seldom reflected in its price, or in that of the farm products that consume so much of it. That cannot go on for long.

None of these changes will necessarily be easy to achieve. Most cost money, and politicians are often reluctant to find it. The ►►



But transpiration is harder to deal with than perspiration

▶ market would help, if it were allowed to. But it will take decades to introduce a system of tradable water rights, let alone market pricing, in most poor countries.

Meanwhile, investment is badly needed almost everywhere. In the developed markets of the United States, where water rights are traded, prices have been rising fast. But since water in most places is usually priced so low, if at all, the revenue generated is seldom enough to maintain or replace even existing infrastructure. Even in America the bills will be dauntingly large. Analysts at Booz Allen Hamilton tried in 2007 to estimate how much investment would be needed in water infrastructure to modernise obsolescent systems and meet expanding demand between 2005 and 2030. Their figure for the United States and Canada was \$6.5 trillion. For the world as a whole, they reckoned \$22.6 trillion.

Such calculations are made more difficult by the uncertainty surrounding climate change. The Intergovernmental Panel on Climate Change said in 2008 that more precipitation was likely in high latitudes and some wet tropical areas, less in dry regions in mid-latitudes and the dry tropics. Rain was likely to become more intense and variable in many places, and farmers in the arid and semi-arid tropics were likely to become more vulnerable. On balance, disadvantages were likely to outweigh benefits.

Few people have dwelt on the worst possibility, even if it is highly unlikely to come about: that the extra water vapour held by a warmer atmosphere might set in train a runaway greenhouse effect in which temperatures rose ever faster and tipping-points for, say, the melting of ice sheets were reached. This possibility has received little consideration outside academia, perhaps because less improbable con-

sequences of climate change provide enough to be gloomy about. The wise conclusion to be drawn may be that all planning should allow for greater uncertainty, and probably also greater variability, so every plan will need to have a greater degree of resilience built into it than in the past.

### The art of the possible

But, setting aside the possibility of a runaway greenhouse effect, would the measures outlined above be enough to bring supply and demand for water harmoniously into balance by 2050, when the world's population is presumed to stop growing? The McKinsey report published last year by the 2030 Water Resources Group believes that such an outcome is indeed possible, and at "reasonable cost", if the right actions were taken. Adopting an economic approach, the report develops what it calls a water availability cost curve. This has the merit of distinguishing be-

tween the measures that could be adopted cheaply in a country like India and those that would be more expensive, some of them vastly more. Yet it hardly constitutes the discovery of an aqueous elixir.

The difficult problem that still awaits an answer is how to get higher yields from food crops without a commensurate rise in the loss of water through evapotranspiration. This is the crucial issue if water is to be used sustainably by farmers, the biggest consumers in the thirstiest activity in the most populous parts of the world. Plenty of gains can be made by adopting no-till farming, drip irrigation, genetically modified crops and so on, but they all come to an end after a while, leaving any gain in yields matched by gains in ET. No one has yet found a convincing way of producing dramatically more food with less water. Genetic modification can help by producing drought-resistant breeds, but not, it seems, by altering the fundamentals of transpiration.

Unless some breakthrough occurs in getting the salt out of sea water, the best hope of a happy marriage between supply and demand comes from much greater restraint among water-users. This is what the farmers of Andhra Pradesh and parts of China are already doing. It is also what they, and many others, will be forced into if they do not do it of their own accord—unless, that is, they leave the land altogether. For, one way or another, supply and demand will find an equilibrium. The greatest chance of it being a stable and fairly harmonious one is the spread of democratic self-management among informed farmers. That would not solve all water problems, but it would solve the biggest. ■

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