Water is a Local Issue

Understanding the Collapse Threshold for Water and its Implications on Micro-watersheds

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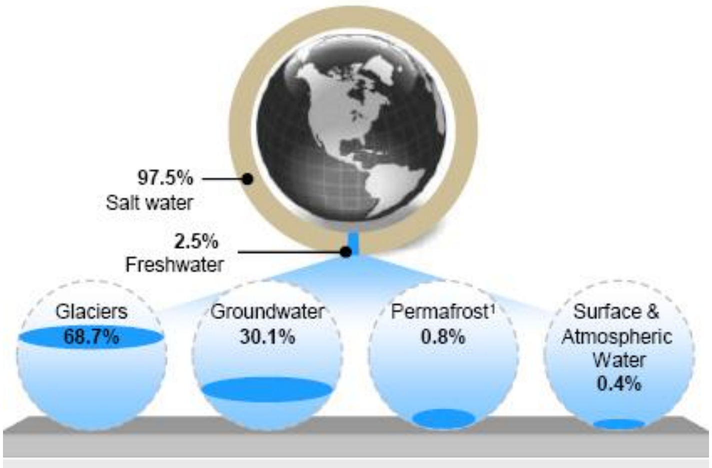
The report drawn up by the World Commission on Water for the 21st Century says "the arithmetic of water simply does not add up". It says that within 20 years, the world is likely to need much more water to grow the food it needs than it will be able to find.[1]

The Earth's water resources can be visualised as various stocks and flows in the hydrological cycle – in many forms and varying quality. There is a stock of approximately 1.4 billion cubic kilometers of water. Only 2.5% of this water is not salty, and two-thirds of that is trapped in the icecaps and glaciers. Of what is left, about 20% is in remote areas and most of the rest comes at the wrong time and in the wrong place, as with monsoons and floods. The amount of fresh water available for human use is less than 0.08% of all the water on the planet. Only small fractions are readily available to humans in river flows, accessible surface lakes and groundwater, soil moisture, or rainfall[2].

Figure 1 Breakdown of global fresh water reserves



Credit: Grail Research, Water – The India story, 2009

About 70% of the fresh water is already used for agriculture, and the report says the demands of industry and energy will grow rapidly. The World Water Council report estimates that in the next two decades the use of water by humans will increase by about 40%, and that 17% more water than is available will be needed to grow the world's food.

[1] World Water Commission for 21st Century Report, 2000
[2] Shiklomanov IA (1993) World Fresh Water Resources. Water in Crisis, ed PH Gleick (Oxford Univ Press, Oxford)

When we consider the total volume of water on Earth, the concept of "running out" of water at the global scale is an unlikely scenario[3]. There are huge volumes of water—many thousands of times the volumes that humans appropriate for all purposes. In the early part of this century, total global withdrawals of water were approximately 3700 km^3 per year, a tiny fraction of the estimated stocks of fresh water[4].

In order to understand and evaluate human uses of water we need to look at local stocks and flows of water at micro and milli-watersheds level, and the impact of appropriations at various scales. Ehrlich PR et al in 1996[5] concluded that humans already appropriate over 50% of all renewable and "accessible" freshwater flows, including a fairly large fraction of water that is used in-stream for dilution of human and industrial wastes. These are the "renewable" flows of water. In theory, the use of renewable flows can continue indefinitely without any effect on future availability. However, some uses of water will degrade the quality of these flows to a point where constraints will appear that will alter the kinds of possible use.

Regional/local water scarcity is a significant and growing problem. The United Nations has defined water stress as regions where water consumption exceeds 10% of renewable freshwater resources. Other definitions set per-capita availability standards for defining scarcity. However, no single measure can adequately describe the character of water scarcity. Yet it is increasingly apparent that some regions are experiencing limits to growth in water use due to natural, ecological, political, or economic constraints.

Outlook for India:

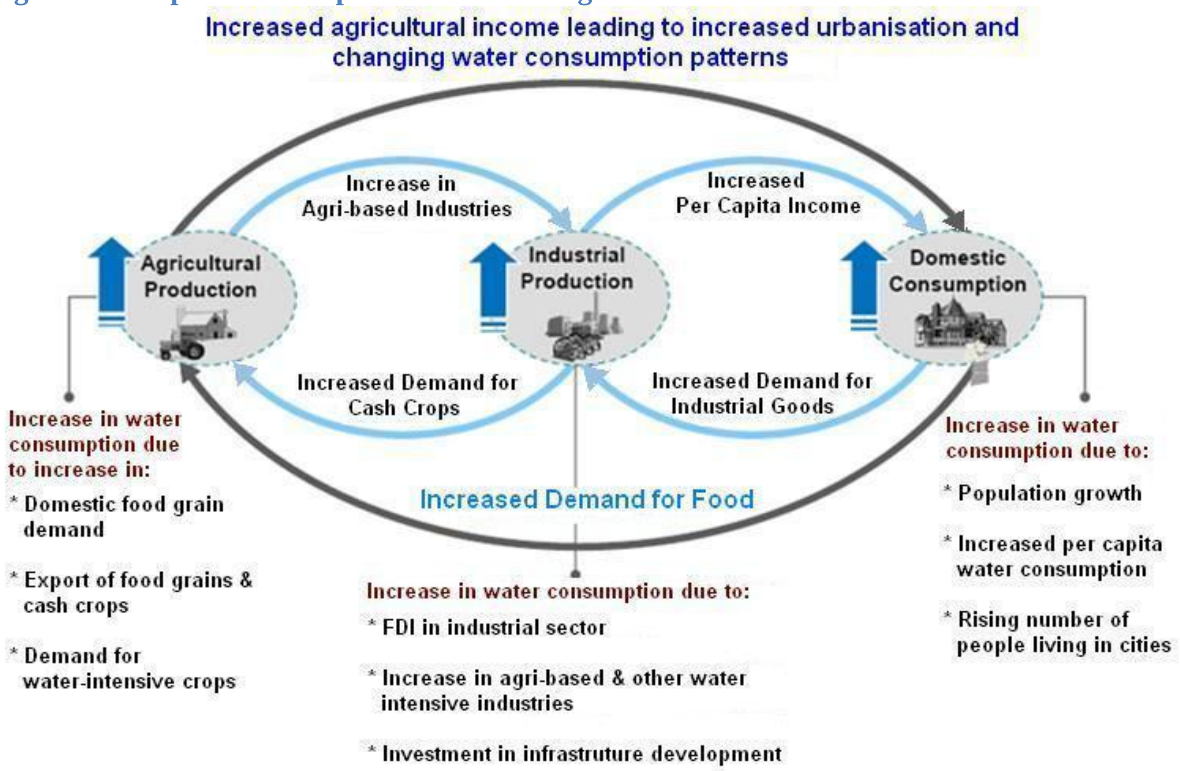
India's demand for food grain will grow from 178 MM mt in 2000 to 241 MM mt in 2050. Increase in exports: Value of agricultural exports of India have tripled from $5.6 Bn in 2000 to $18.1 Bn in 2008. Change in consumption pattern of agricultural products: Demand for agricultural products with high water footprint is projected to rise with increased disposable income and urbanization. Contribution of non-food grain (sugarcane, fruits and vegetables, etc.) and animal productsin daily food intake for an individual is expected to grow from 35% in 2000 to 50% 2050.[6]

As land and water become scarce, competition for these vital resources intensifies within societies, particularly between the wealthy and those who are poor and dispossessed. The shrinkage of life-supporting resources per person that comes

[3] The World's Water 2008-09, Chapter 1 by Meena Palaniappan and Peter H.Gleick forms the back-bone of this discussion papar. Repeated references to this work has been omitted to retain the readability
[4] Gleick PH (2006) The World's Water 2006–2007 (Island Press, Washington, DC),
[5] Postel SL, Daily GC and Ehrlich PR (1996) Human appropriation of renewable fresh water. Science 271:785–788.
[6] Grail Research, Water – India Story 2009

with population growth is threatening to drop the living standards of millions of people below the survival level, leading to potentially unmanageable social tensions[7].

Figure 2: Complex Landscape for Water Management



Credit: Grail Research, Water – The India story, 2009

In a large developing country such as India, the links between water consumption across sectors creates a complex landscape for water management. The demand and consequent consumption of water is driven by complex interactions between agricultural production, industrial production and domestic consumption. Increase in domestic food grain demand, export of food grain and cash crops coupled with demand for water intensive crops, pushes the demand for water in agriculture production system.

[7] Lester Brown, 2009, Plan B 4.0,

Increased agricultural income leading to increased urbanization and changing water consumption patterns. Simultaneously an increase in agri-based industries pushes the industrial production, which in turn raises per capita income. An increase in per capita income reflects as increased demand for industrial goods as well as food, which results in further increase in agricultural and industrial production, increasing the water consumption in these sectors. This further galvanises the domestic water consumption due to population growth, increased per capita water consumption, urbanisation and migration to cities.

The three reinforcing processes feed into each other and create a vicious cycle of ever increasing demand for water.

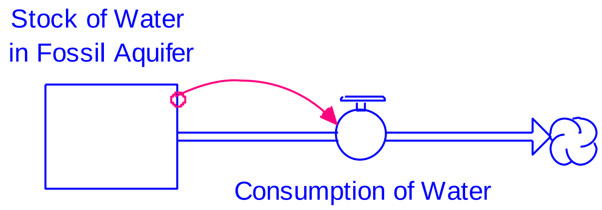
This is direct water consumption. We cannot escape the water intensity of food production. We drink on average close to 4 litres of water per day, directly or in coffee, juice, soda, wine, and other beverages. But it takes 2,000 litres of water to produce the food we consume each day—500 times as much as we drink. In effect we "eat" 2,000 litres of water each day.[8]

If we are to solve the issues of water shortages we necessarily need to understand the dynamics of water at the level of local watersheds. Further we propose that water should be seen as both renewable and non-renewable resource as discussed later in this paper.

Key Characteristics of Renewable and Non-renewable Resources.

When dealing with resources, it is important to distinguish between renewable and non-renewable resources. The renewable resources are flow or rate limited; non-renewable resources are stock limited[9] .

Figure 3 Non Renewable Resource Diagram

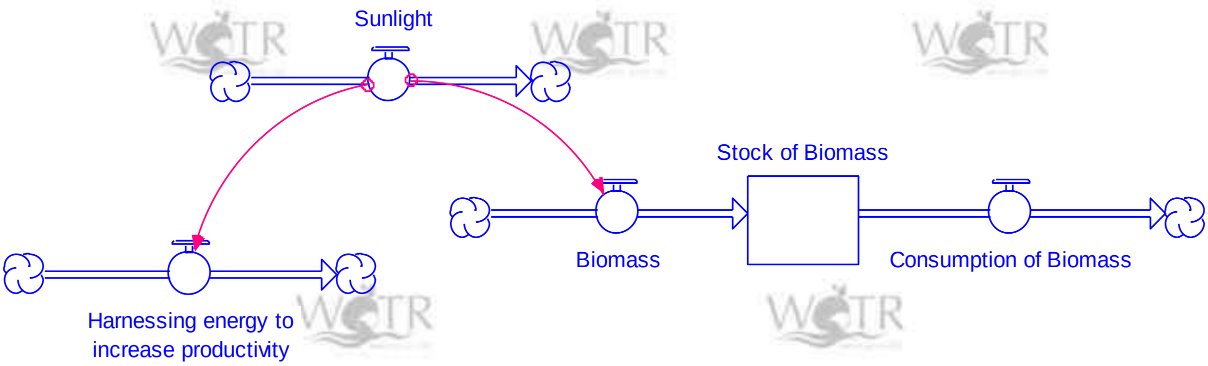


[8] Lester Brown, Plan B 4.0, 2009
[9] Thinking is Systems, Donella Meadows 2007

Credit: WOTR Analysis

Stock-limited resources, like fossil fuels, can be depleted without being replenished on a timescale where they could be of any practical use. Stocks of oil, for example, accumulated over millions of years; the volume of oil stocks is thus effectively independent of any natural rates of replenishment because such rates are so slow.

Figure 4 Renewable Resource Diagram



Credit: WOTR Analysis

Conversely, renewable resources, such as solar energy, are virtually inexhaustible over time, because their use does not diminish the production of the next unit. Such resources are, however, limited by the flow rate, i.e., the amount available per unit time. Our use of solar energy has no effect on the next amount produced by the sun, but our ability to capture solar energy is limited to the rate at which it is delivered.

Water demonstrates characteristics of both renewable and non-renewable resources. This dual characteristic of water has implications for systemic understanding some vital issues pertaining to water availability and its management.

Water is largely a renewable resource with rapid flows from one stock (and form) to another. The human use of water typically has no effect on natural recharge rates. But there are also fixed and isolated stocks of local water resources that are being consumed at rates far faster than natural rates of renewal.

Most of these non-renewable resources are groundwater aquifers—often called "fossil" aquifers because of their slow-recharge rates. Tiwari et al[10] have pointed out that substantial percetange of water used in India comes from non-renewable groundwater withdrawals. This water ends up in the oceans, incrementally raising sea levels, but substantially depleting groundwater stocks. Some surface water storage in the form of lakes or glaciers can also be used in a non-renewable way where consumption rates exceed natural renewal, a problem that may be worsened by climate change.

Consumptive vs. Non-consumptive Uses

[10] Tiwari VM, Wahr J, Swenson S (2009) Dwindling groundwater resources in northern India, from satellite gravity observations. Geophys Res Lett

Another key factor in evaluating the availability of a resource is whether resource use is "consumptive" or "non-consumptive."

Not all uses of water are consumptive. Consumptive use of water typically refers to uses that make that water unavailable for immediate or short-term reuse within the same watershed. Such consumptive uses include water that has been evaporated, transpired, incorporated into products or crops, heavily contaminated, or consumed by humans or animals. This understanding has serious implications for isolated rural communities that exist in rain-fed regions.

Some stocks of water can be consumed locally, making them, effectively, non-renewable resources. When withdrawals are not replaced within a timescales, which are in line with the natural rhythms of the community's activities, eventually that stock becomes depleted.
The water itself remains in the hydrologic cycle, in another stock or flow, but it is no longer available for use in the region originally found.

There are also many non-consumptive uses of water. This water recycles into the overall hydrological cycle and could be subsequently available in a region. A part of the water used to irrigate the fields in the upper catchment finds its way to the percolation tanks.

Substitutability.

Another important characteristic of resource availability is the potential to substitute alternatives for non-renewable sources.

As oil production declines and prices increase, alternate sources of energy become increasingly attractive. In this sense, any depletable resource must be considered a transition option, useful only as long as its availability falls within economic and environmental limits. Water, like energy is used for a wide variety of purposes.

And like energy, the efficiency of water use can be greatly improved by changes in technologies and processes. Unlike oil, however, fresh water is the only substance capable of meeting certain needs. And therefore, unlike energy, water has no substitutes for most uses.

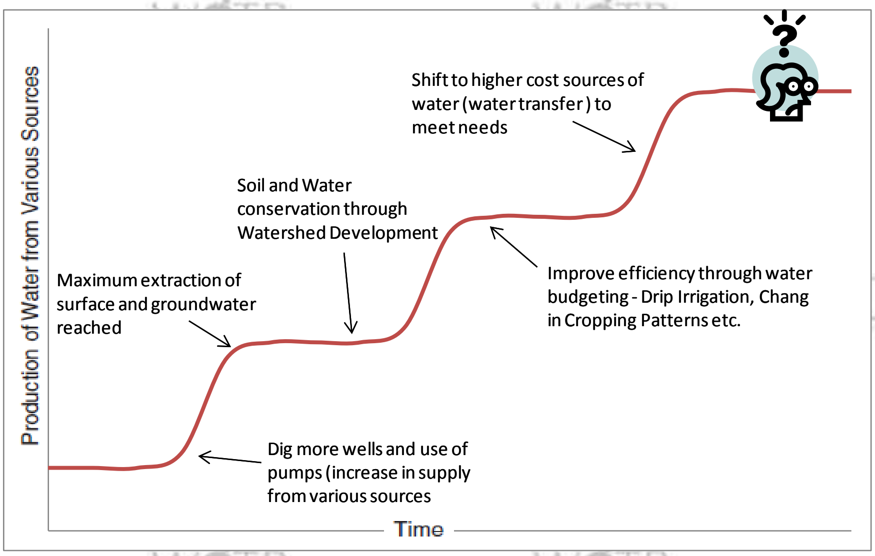
When limits to water availability in a given region (or watershed) are reached, there are a few possible options to meet additional needs:

i. reducing demand i.e, shifting to low water consuming crops; more efficient water use – drip irrigation etc.
ii. substituting one use of water for another that has higher economic or social value,
iii. physically moving the demand for water to a region where additional water is available; or
iv. investing in a higher priced source of supply, including bulk imports or transfers of water. In this case, the cost of new supply, including the cost of transporting water, is a limiting factor.
v. And when this becomes a constraint, resort to seasonal or permanent migration

A relevant concept to resource management, therefore, is the introduction of a “backstop” technology when the price of the resource rises[11].

For example as oil production peaks and then declines, the price of oil will rise in the classic “supply/demand” economic response. Prices will continue to rise till a substitute, or backstop, for oil becomes economically competitive, at which point prices will stabilize at the new backstop price. Nordhaus[6] noted that a backstop alternative is one capable of meeting the demand and that has a virtually infinite resource base.

Figure 5 Potential Water production scenario in a Watershed



Credit: WOTR Analysis and The World’s Water 2008-09, Chapter 1 pg 11

Similarly, for water, as cheaper sources of water are depleted or allocated, more and more expensive sources must be found and brought to the user, either from new supplies or reallocation of water among existing users. Fig. 5 graphs a potential water production scenario in a watershed, where incremental supply increases through supply side projects, e.g., groundwater harvesting, in-stream flow allocation, and reservoir construction are layered upon each other until the maximum cost-effective extraction of surface and groundwater is reached.

Ultimately, the backstop price for water will also be reached. Unlike oil, however, which must be backstopped by a different, renewable energy source, the ultimate water backstop is still water. That makes water a bigger issue than, say oil.

Transportability.

The “transportability” of water—is particularly relevant to understanding the challenge of water availability. Water is very expensive to move any large distance, compared to its value.

We therefore need to focus on local water scarcity and challenges. In regions of water scarcity, the apparent nature of water constraints are already apparent. Because the costs of transporting bulk water from one place to another are so high, that once a region’s water use exceeds its renewable supply, it begins to tap into non-renewable resources, such as slow-

[11] Nordhaus WD (1973) The allocation of energy resources.

recharge aquifers. Once extraction of water exceeds natural rates of replenishment, the only long-term options are to reduce demand to sustainable levels, move the demand to an area where water is available, or to shift to increasingly expensive sources, such as desalination or imports of food produced in regions with adequate water supplies, the transfer of so-called virtual water.

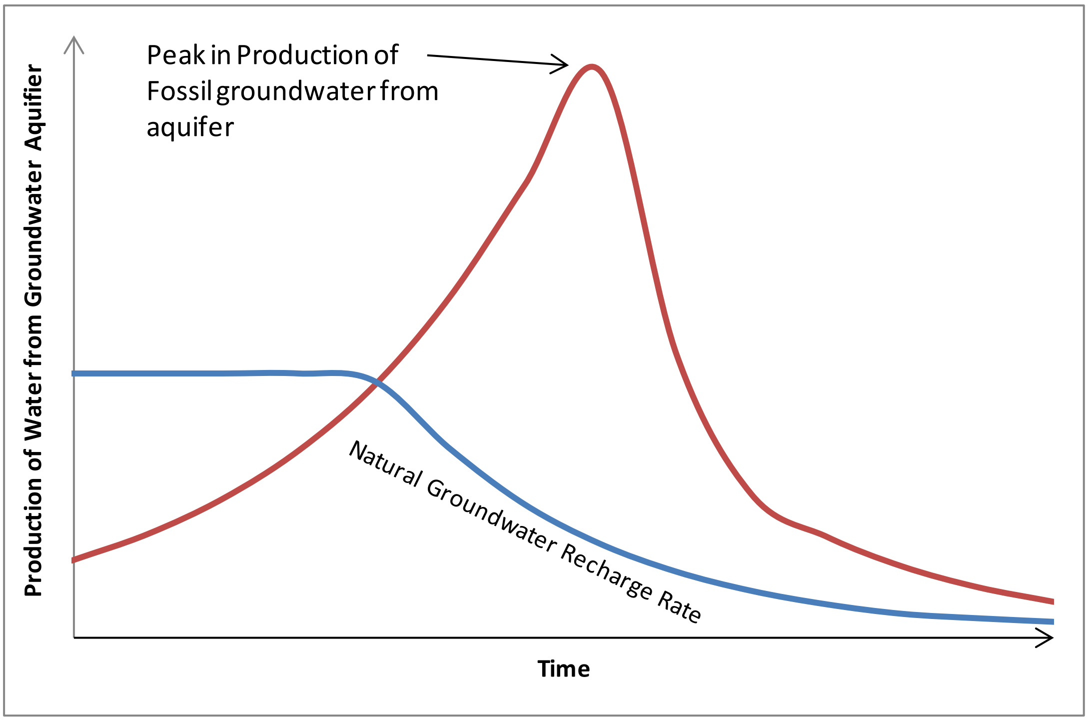
Three Concepts of Collapse Threshold for Water

We offer here three definitions where the concept of a Collapse Threshold is useful in the context of water resources and we introduce a term that is useful when thinking about maximizing the multiple services that water provides: "ecological collapse threshold for water." These concepts of collapse threshold for water should help drive important paradigm shifts in how water is used and managed.

Collapse Threshold for Renewable Water.

A significant fraction of total anthropogenic use of water comes from water taken from renewable flows of rainfall, rivers, streams, and groundwater that are recharged in a relatively short time. Use of water does not affect the ultimate renewability of the resource. Just because a particular water source is renewable, does not mean that it is unlimited. The first collapse threshold water constraint is the limit on total water that can be withdrawn from a system. The ultimate limit is the complete renewable flow.

Figure 6 Production Profile of Renewable Water from Watershed



Credit: WOTR Analysis and The World's Water 2008-09, Chapter 1 pg 10

As shown in Fig. 6, when the production of renewable water from a watershed reaches 100% of renewable supply, it forms a classic logistics curve, similar to a biological carrying capacity model. Each watershed only has a certain amount of renewable water supply that is replenished every year. If the annual production of renewable water from a watershed increases exponentially, it approaches the natural limit of the total annual renewable supply of water. The appropriate practical limit may be substantially less than this and explained through Ecological Collapse Threshold for Water.

Increasing annual renewable water use to the theoretical renewable limit would result in tremendous ecological, environmental, and human damage.

Renewable water systems can sometimes be turned into non-renewable systems through physical or chemical processes.

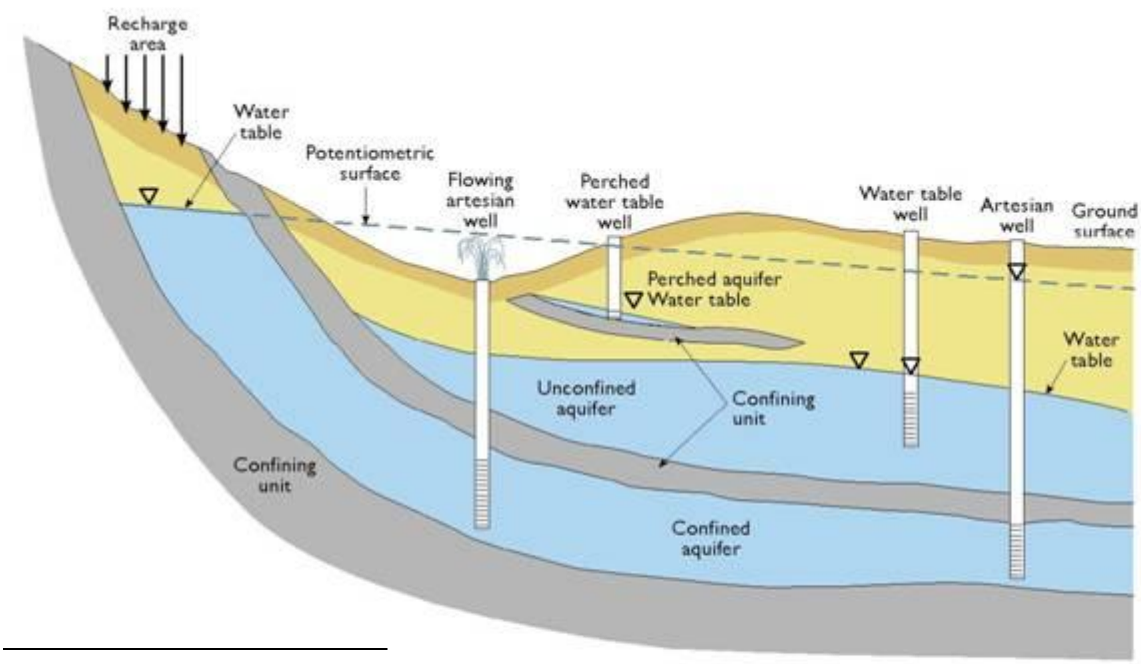
Collapse Threshold for Non-renewable Water.

In some watersheds, like those found in Indian Deccan Plateau, a substantial amount of current water use comes from stocks of water that are effectively non-renewable. The groundwater aquifers below the basaltic rock in these systems have a very slow-recharge rates. Then there are groundwater systems that lose their ability to be recharged when over-pumped due to compaction or other physical changes in the basin.

When the use of water from a groundwater aquifer far exceeds the natural recharge rate, this stock of groundwater will be quickly depleted. A renewable aquifer can become non-renewable, when groundwater becomes contaminated with pollutants rendering the water unusable.

Sustained production of water beyond natural recharge rates becomes increasingly difficult and expensive as groundwater levels drop, leading to a peak in production, followed by diminishing withdrawals and use. This kind of unsustainable groundwater use can be found in numerous basins in India[12]. Tiwari[13] et al. estimate that nonrenewable use of water in India averaged around 8% of India's total water withdrawals, per year between 2002 and 2008.

Figure 7 Ground Water Aquifers



[12] Chatterjee R, Purohit RR (2009) Estimation of replenishable groundwater resources of India and their status of utilization.
[13] Tiwari VM, Wahr J, Swenson S (2009) Dwindling groundwater resources in northern India, from satellite gravity observations.

Credit:http://www.douglas.co.us/water/images/Denver_Basin_Aquifers_clip_image004.jpg, accessed on 02-11-10

As shown in Fig. 7, even when the rate of withdrawals from a groundwater aquifer passes the natural recharge rate for the aquifer, the production of water from the aquifer can continue to increase until a significant portion of the groundwater has been harvested. After this point, deeper boreholes and increased pumping will be required to harvest the remaining amount of water. The increase in capital required and cost of production potentially reduces the rate of production of water.

What is even more alarming is that the production of water from the aquifer will continue to increase until all economically affordable groundwater is harvested, after which the production of water drops quickly. In both these cases, the important point is that extraction will not fall to zero, but to the renewable recharge rate where economically and physically sustainable pumping is possible.

In some places, climate change will affect the nature and magnitude of collapse threshold for water. The North Indian alluvial planes, where local communities are currently dependent on river runoff from glacier melt, the loss of glaciers in coming years will lead to a “collapse threshold for non-renewable water” effect – reduced water supply over time.

Communities dependent on groundwater recharge that suffer a decrease in recharge rate will also experience an effect similar to collapse threshold for water. In this case, the concept of collapse threshold for water is slightly different: It is not affected by the magnitude of anthropogenic activity, but by physical or climatic factors that diminish the rate of, or potential for, replenishment. It is similar to collapse threshold, in a sense that when the stock is gone, alternative sources will have to be found.

Nowhere are falling water tables and the shrinkage of irrigated agriculture more dramatic than in Saudi Arabia, a country as water-poor as it is oil-rich. After the Arab oil export embargo in the 1970s, the Saudis realized they were vulnerable to a counter embargo on grain. To become self-sufficient in wheat, they developed a heavily subsidized irrigated agriculture based largely on pumping water from a deep fossil aquifer.[14][15]

After being self-sufficient in wheat for over 20 years, in early 2008 the Saudis announced that, with their aquifer largely depleted, they would reduce their wheat planting by one eighth each year until 2016, when production will end. By then Saudi Arabia will be importing roughly 15 million tons of wheat, rice, corn, and barley for its population of 30 million. It is the first country to publicly project how aquifer depletion will shrink its grain harvest.[16]

Water shortages are even more serious in India, where the margin between food consumption and survival is so precarious. To date, India’s 100 million farmers have drilled more than 21 million wells, investing some $12 billion in wells and pumps. In August 2004 Fred Pearce reported in *New Scientist* that “half of India’s traditional hand-dug wells and millions of shallower tube wells have already dried up, bringing a spate of suicides among those who

[14] Craig S. Smith, “Saudis Worry as They Waste Their Scarce Water,” *New York Times*, 26 January 2003.
[15] Plan B 4.0 2009, Lester Brown
[16] Andrew England, “Saudis to Phase Out Wheat Production,” *Financial Times*, 10 April 2008;

rely on them. Electricity blackouts are reaching epidemic proportions in states where half of the electricity is used to pump water from depths of up to a kilometer."[17, 10]

As water tables fall, well drillers are using modified oil-drilling technology to reach water, going down a half mile or more in some locations. In communities where underground water sources have dried up entirely, all agriculture is now rain-fed and drinking water must be trucked in. Tushaar Shah, who heads the International Water Management Institute's groundwater station in Gujarat, says of India's water situation, "When the balloon bursts, untold anarchy will be the lot of rural India."[12, 10]

Growth in India's grain harvest, squeezed both by water scarcity and the loss of cropland to non-farm uses, has slowed since 2000. A 2005 World Bank study reports that 15 percent of India's food supply is produced by mining groundwater. Stated otherwise, 175 million Indians are fed with grain produced by water mining.[12, 10]

Collapse Threshold for Ecological Water.

Pressures on freshwater ecosystems

A wide range of human uses and transformations of freshwater or terrestrial environments has the potential to alter, sometimes irreversibly, the integrity of freshwater ecosystems.

Human Activity	Potential Impact	Function at Risk
Population and consumption growth	Increases water abstraction and acquisition of cultivated land through wetland drainage. Increases requirement for all other activities with consequent risks	Vitually all ecosystem functions including habitat, production and regulation functions
Infrastructure development (dams, dikes, levees, diversions etc)	Loss of integrity alters timing and quantity of river flows, water temperature, nutrient and sediment transport and thus delta replenishment, blocks fish migrations	Water quantity and quality, habitats, floodplain fertility, fisheries, delta economies
Land conversion	Eliminates key components of aquatic environment, loss of functions; integrity , habitat & biodiversity, alters runoff patterns, inhibits natural recharge, fills water bodies with silt	Natural flood control, habitats for fisheries and waterfowl, recreation, water supply, water quantity and quality
Overharvesting and exploitation	Depletes living resources, ecosystem functions and biodiversity (groundwater depletion, fisheries collapse)	Food production, water supply, water quality and water quantity
Introduction of exotic species	Out competition of native species, alters production and nutrient cycling, loss of biodiversity	Food production, wildlife habitat, recreation

[17] Fred Pearce, "Asian Farmers Sucking the Continent Dry," *New Scientist*, 28 August 2004.

Release of pollutants to land, air or water	Pollution of water bodies alters chemistry and ecology of rivers, lakes and wetlands. Greenhouse gas emissions produce dramatic changes in runoff and rainfall patterns	Water supply, habitat, water quality, food production. Climate change may also impact hydropower, dilution capacity, transport, flood control

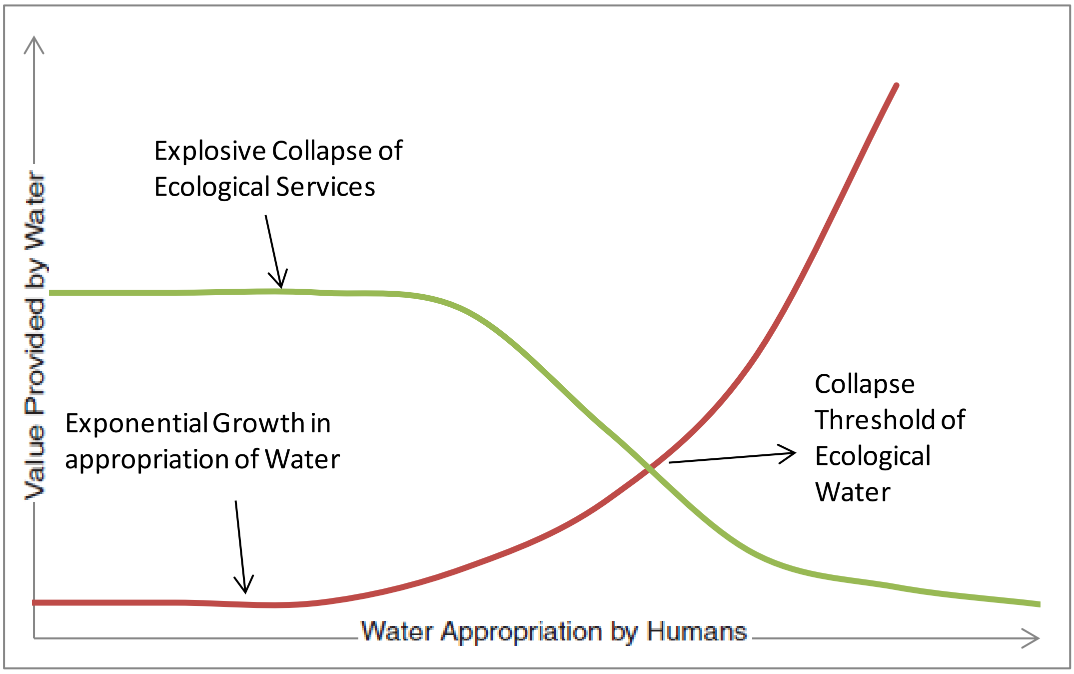
Credit: Extracted form the Executive Summary of the WWDR. IUCN, 2000. Vision for Water and Nature. *A World Strategy for Conservation and Sustainable Management of Water Resources in the 21st Century - Compilation of All Project Documents*. Cambridge.

For many watersheds – particularly the resource fragile rainfed regions of peninsular India – a more immediate and serious concern than running out of water is exceeding a point of water use that causes serious or irreversible ecological damage.

Water provides many services. It sustains human life and commercial and industrial activity. It is also fundamental for the sustenance for animals, plants, habitats, and environmentally dependent livelihoods.

Each new incremental supply project that captures water for human use and consumption decreases the availability of that source to support ecosystems and diminishes the capacity to provide services. The water that has been temporarily appropriated or moved was once sustaining habitats and terrestrial, avian, and aquatic plants and animals. By some estimates, humans already appropriate almost 50% of all renewable and accessible freshwater flows[18], leading to significant ecological disruptions.

Figure 8 Ecological Collapse Threshold for Non Renewable Water



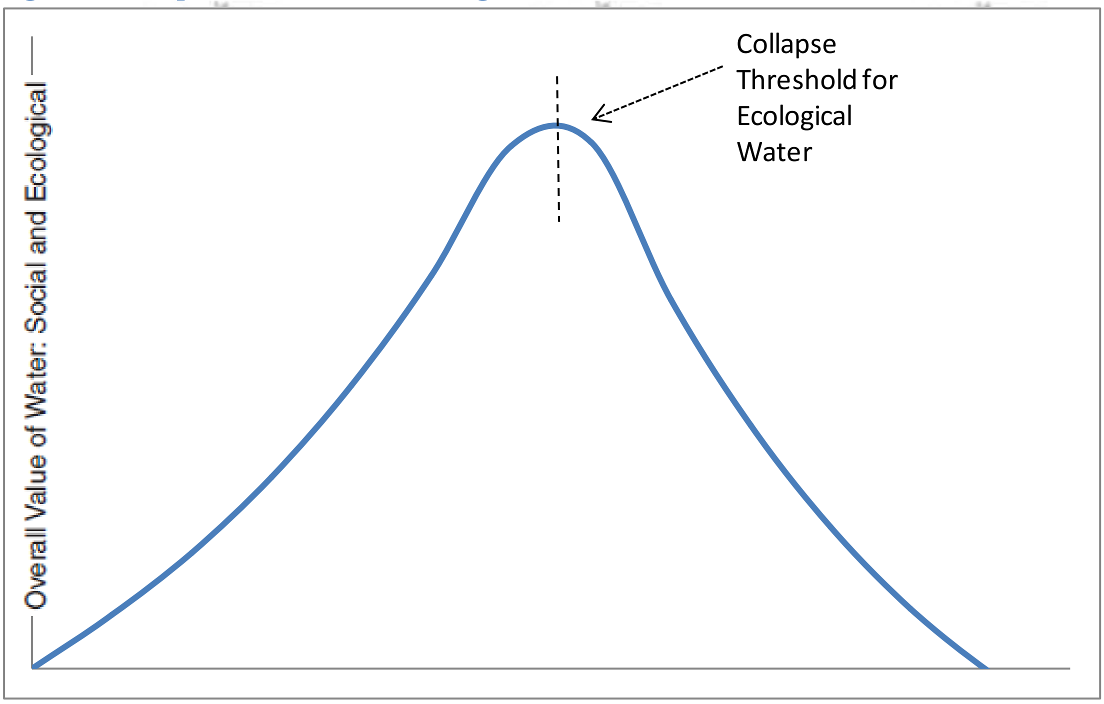
Credit: WOTR Analysis and The World's Water 2008-2009, Chapter 1 pg 12

[18] Postel SL, Daily GC, Ehrlich PR (1996) Human appropriation of renewable fresh water.

Fig. 8 is a simplified graph of the value that humans obtain from water produced through incremental increases in supply (e.g., drinking water and irrigation), plotted against the declining value of the ecological services that were being satisfied with this water. The graph assumes that ecological services decrease as water is appropriated from watersheds.
The rate or severity of ecological disruptions increases with increasing amounts of water appropriated. Because ecological services are not easily valued in monetary terms, the y axis should be considered the overall (economic and noneconomic) "value provided by water."

At a certain point, the value of ecological services provided by water is equivalent to the value of human services satisfied by that same use of water. After this point, increasing appropriation of water leads to ecological disruptions beyond the value that this increased water provides to humans (the slope of the decline in ecological services is greater than the slope of the increase in value to humans). We define this point to be peak ecological water—where society will maximize the total ecological and human benefits provided by water. As shown in Fig. 9, the overall value of water, combining ecological and social benefits, then declines as human appropriation increases.

Figure 9 Collapse Threshold for Ecological Water



Credit: WOTR Analysis and The World's Water, Chapter 1 pg 12

Economists and resource analysts have long noted the difficulty of quantifying this point because of problems in assigning appropriate valuations to each unit of water or each unit of ecosystem benefit in any watershed. But the mistaken assumption that such values are zero has led to them being highly discounted, underappreciated, or ignored in 20th century water policy decisions.

Collapse Threshold for Water in India

Data on total water use is sparse. Few countries or regions collect such data because of the physical or political difficulties of accurately measuring water withdrawals from countless diverse sources to meet agricultural, industrial, commercial, and domestic needs. As a result, identifying peak water limits will be difficult.

Conclusions: Implications of Collapse Threshold for Water

Water is fundamental for ecosystem health and for economic productivity, and for many uses it has no substitutes. We offer three separate contexts to the collapse threshold for water – for renewable and non-renewable water systems and also the concept of collapse of ecological water. We also raise the possibility that many regions in India may have already passed the point of peak water.

The concept of collapse threshold for water does not mean we will run out of water. Water is a renewable resource and is not consumed in the global sense: Hence, water uses within renewable peak limits can continue indefinitely. But not all water use is renewable; indeed some water uses are non-renewable and unsustainable. Groundwater use beyond normal recharge rates follows a bell shaped curve with a peak or threshold after which there is a rapid decline in water production. Such collapse threshold for non-renewable water problems are increasingly evident in major groundwater basins with critical levels of overdraft, such as the Ogallala and California's Central Valley in the United States, the North China Plains, and in numerous states in India, such as Andhra Pradesh, Rajasthan, and Tamil Nadu. Collapse threshold for ecological water refers to the point after which the cost of disruptions that occur in the ecological services that water provides exceeds the value provided by additional increments of water use by humans for economic purposes. Defined this way, many regions of the world have already surpassed peak ecological water—humans use more water than the ecosystem can sustain without significant deterioration and degradation.

The concepts around collapse threshold for water are also important in driving some paradigm shifts in the use and management of water. There are growing efforts to quantify ecological limits and to develop policies to restore water for ecosystem services in basins where serious ecological disruptions have already been recognized.

Improvements in the ability to identify groundwater basins suffering from non-renewable withdrawals are increasing the pressure on water managers to reduce withdrawals to more sustainable levels, or to better integrate surface and groundwater management. And the realization that there are limits to renewable water use are forcing new discussions about improving water-use efficiency and developing innovative technologies for water treatment and reuse as alternatives to expanding traditional supply projects to further mine overtapped renewable water sources.

The bad news is that we are increasingly reaching collapse threshold for water. The good news is that recognizing and understanding these limits can stimulate innovations and behaviours that can reduce water use and increase the productivity of water, shifting water policy toward a more sustainable water future.