Water: a global issue with local solutions [a global crisis with multiple local solutions]

It is easy to forget when you rise in the morning and wash your face, take a shower or flush a toilet that water holds a central place in our lives. It is just there. We have it at our fingertips, on demand, cool, clear and clean. There is no worry that the next drink will cause us harm, or worry that using a flush too many will prevent doing the dishes. We take our water for granted, forgetting that there is a massive infrastructure in place to get us that easy open tap water.

Two years ago a war started in Syria. It followed a 5 year drought affecting the interior of the country to the east of the Mediterranean highlands. Most of Syria is dry, but this drought has proven exceptional, driving many from their homes in the Euphrates River Valley, becoming effectively wards of the state in the western regions. Displacement builds tensions. Tensions about water in Syria are constantly high. The Euphrates rises in the eastern Turkish highlands, home of Kurdish peoples, and one of the underdeveloped regions of that country. The Turks hoped to revitalize the economy of that region by building massive dams on the river for irrigation, but this has an adverse effect on the downstream countries of Syria and Iraq, so delicate negotiations took place related to water retention and release to minimize conflict. These are often based on years of normal flow, but in drought years all parties suffer, though Turkey controls the tap. The result of drought and Turkish water control is the Syrian civil war.

A glance around the world shows that water conflicts lie at the heart of many violent outbreaks. Iraq, Afghanistan and troubles in Israel/Palestine are regional examples. A survey of countries around the Sahara Desert read like a set of impending or actual disasters with water as a core theme; Egypt, Libya, Tunisia, Algeria, Morocco/Western Sahara, Mali, Niger, Northern Nigeria, Chad, Sudan (Darfur) and Eritrea all have water involved. And anytime water is an issue so is food. An Ethiopian proverb sums up the water and food based problems: *Starving people eat their leaders*. The impact of climate change, altering the profile of rainfall on the planet, could kick off a series of water wars that no amount of UN activity or US and European intervention can prevent. At the same time, if we really understand the nature of the hydrologic cycle in most of these places, there are things that can be done to improve the supply of water and therefore food. This is the theme of this chapter: how do we understand local hydrologic cycles and work with them to come up with locally appropriate solutions.

Where does your water come from?

The Shenandoah Valley lies between the Blue Ridge Mountains to the east and the Shenandoah Mountains to the west. These two ridges act as barriers to moist air coming from the Great Plains and Mississippi Valley, or from the Gulf of Mexico, raising clouds and promoting rain. The valley itself is actually rather dry, getting only two thirds of the rainfall normal on either side of the mountains, about 34 inches a year. It is prone to occasional droughts, not as severe as the ones in the American southwest or the Sahel of Africa, but troubling none the less.

Water for the city of Harrisonburg is captured in the Shenandoah Mountains along the West Virginia border in the George Washington National Forest. The forest serves as a natural sponge, capturing, filtering and protecting the water until its arrival in Switzer Dam and a smaller reservoir on the Dry River just to the north. The dams buffer seasonal fluctuations in the water flow of the Dry River. The Dry River serves as a pipe from these dams downstream to a location near Blue Hole where a pipe captures a portion of the flow and takes it to the city of Harrisonburg. The city then treats the water making sure that no disease organisms can reach your tap and pumps it to high points in the town. Every town has their local water tower or towers that allow a gravity feed system to reach houses, businesses, industries and fire hydrants. The water going to toilets, sprinklers, sinks and drinking fountains is all the same treated water from the Harrisonburg water treatment plant. It takes a lot of pipes, tanks and pumps to get that water to you for your morning shower. And what do you do after using the water? It goes in another pipe and disappears.

For the most part we do not give that water a second thought, but as with any item on the planet there really is no away. The water has to go someplace and in this case it is the Harrisonburg/ Rockingham Wastewater Treatment Plant near Mt. Crawford. This is a nearly new facility. Harrisonburg and the surrounding development area have grown substantially during the last two decades, the expansion of James Madison University playing a large part in that growth, and more people mean more water. The treatment plant that was in place to meet the criteria set up by the 1972 Clean Water Act had a daily treatment average of 8 million gallons per day, with a peak of 12 million gallons. Agreements between the states in the Chesapeake Bay Watershed mandated a lowering of nitrogen and phosphorus reaching the bay by 40% by 2010, so with the population growth and the need to reduce these two nutrients, the plant required an upgrade. It can now more effectively remove nitrogen and phosphorus from an average of 12 million gallons per day with up to 20 million gallons per day in peak flow. All the water we put in the pipes from our showers, dishwashers, clothes washers, toilets, poultry processing plants and other industries is treated in the same facility, and then the water flows into the North River and downstream, providing a supply for other cities and a back up supply for Harrisonburg itself. The infrastructure of supply, treatment, disposal piping and sewage treatment is significant and expensive. If something goes wrong everyone could suffer.

In rural Rockingham County most household are not connected to the city's system. People there depend on groundwater. The depth to groundwater, and the consistency of groundwater supply, varies greatly depending on location. My own situation can illustrate this. Our farm, which is co-owned by 5 families, has a single well drilled to a depth of 450 feet. The short uppermost part of the well is lined with a six inch PVC liner until rock is reached. A two inch diameter steel pipe with a submersible pump lies within the well at a depth of 380 feet. The water table is about 260 feet deep, though this fluctuates with annual rainfall levels, partly explaining why the pump is placed so deep, and the well goes even deeper. This pump moves water from the well to a pump house containing two pressure tanks that each hold about 50 gallon of water. The pressure tanks buffer flows so the pump can work at its ideal speed and not go on and off with demand. From the pressure tanks the water flows though distribution pipes to the 5 houses and the outside stand pipes used to irrigate gardens and water the cattle.

We do not treat waste water the same as the city. Instead we let nature do the work. The water goes into a septic tank buried outside each house, most hold around 1500 gallons. It stays in these tanks an average of three days and organic matter is broken down and partially consumed by bacteria in the tanks. From there water flows or is pumped to a drain field dug below the winter frost line and distributed through porous pipes into a rock aggregate surrounded by soil. Underground bacteria and soil fauna take care of things from there. If water rises from the drain field, as it does in some places on the farm, the grass takes on a lush deep green color indicative of high nutrient availability. The water infrastructure in a system like ours probably costs the same or slightly more than the household cost of Harrisonburg water supply and treatment. The infrastructure cost in terms of energy and materials involved should not be ignored. We do have one additional disadvantage; we are completely dependent on electricity, without which we have no water.

In many ways our water system spoils us. We do not have to think about water as a regular daily requirement for life as it is. We can get it whenever we want. The harsh reality for over half the world is that they cannot. Water is both a concern and a daily cost in terms of personal labor and finances. This is the reality for all the countries previously mentioned and for the rural poor in Kenya, where this paper goes next.

Water in Kenya: lessons from the summer of 2013

Kenya is a country of extremes. It has harsh deserts, extensive arid and semi-arid bush land, savannah, dry deciduous tropical forest, small patches of wet tropical forest, and high altitude cold forest and tundra-like conditions. In all locations water issues are apparent. Often it is a question of supply, sometimes a question of sanitation and in cities it is a question of a just distribution network. There is no possibility of finding a single answer to the question of water. The answers are always local and so local is where we will look.

High rainfall areas

In western Kenya, just north and east of Lake Victoria, the largest surface area lake in Africa, lies Kakamega County. It is a land of fertile farms and dense population, home to the Abiluhya people, a mixed group of Bantu language speakers thrown into a single ethnic category during the colonial era. The 11 dialect groups, a number that varies depending on whom and how it is determined, share one of the best soil types on the continent that is also supplied with abundant rainfall. Just having rain does not mean that water is readily available. It also depends on the relative wealth and situation of the household. Only two generations earlier the location of a household and farm was determined by access to water. People set up their grass roofed huts as close to the water supply as they could and still keep everything dry during a rain. Fetching water was not an issue, waste water was thrown onto nearby gardens and fields, and sanitation was simply a short trip to the woods, which were never that far away.

As population grew things changed. People occupied land taken from forest or grassland, housing moved from round thatch huts to rectangular mud and wattle homes with metal roofs. These were farther from water, so getting the water to the house became an issue. Some people have resolved this by building roof catchment systems. If they can afford it, gutters catch the runoff and channel it to a pipe that transfers the water to a tank. Poorer households just find an old oil drum or shipping barrel and fill that along with all the other containers on hand during a rain. Wealthier households either build a ferrocement tank or purchase the now common black plastic water tanks that contain from 100 to 10,000 liters each. For poorer households their limited access to storage means that during periods with little rainfall they need to carry water back to their houses. Women bear the bulk of this burden, hiking from the local stream, spring, or if possible a covered spring with 20 liters strapped on their back (Figure 1). Covered springs are protected with a cement cap and tank surrounding the out let to protect the water from contamination by continuous use and animals. They also provide easier ways to channel the water to a jerry can, usually through a steel pipe. Even a 15 minute walk 3 to 4 times a day is an energy sapping activity to accompany farm work, cooking, cleaning and child care.

Figure 1: A covered spring near Eregi, Kakamega County, Kenya

Sanitation issues arise as well. Wastewater is not really an issue. It is easy to pour on nearby crops, a fact that makes the land closest to the house the most fertile. Human feces are the problem. The woods are smaller, if there are any woods at all, so privacy is an issue. Again relative wealth determines how you take care of these needs. Long drop toilets with a cement platform, walls, metal door and roof are found in high income households. Mud and wattle shorter drop toilets with a cloth draped across for privacy is all you find in poorer households. At least there is usually space for these, unlike major cities.

Nairobi

Cities have a different problem. Nairobi is the largest city in the country. Its water system was designed during the colonial era and realistically intended to supply a half million people. Now there are over 3.1 million in the city according to the Kenya Bureau of Statistics in 2009. While many people have tap water in their homes there are no reliable statistics on how many do not. It is easy to see that many do not have accessible tap water. It is also easy to find the nearly ubiquitous water trucks that ply the city streets delivering water to homes of both wealthy and poor. The city's plumbing works, bringing water from reservoirs in the southern slopes of the Aberdare Range, but is far from reliable at the neighborhood level. So households buy water in batches and have it pumped to storage tanks they keep on their roofs or in spaces in their attics. Some households have their own pumps and fill larger tanks on the ground hidden discretely near the house. The majority poor cannot afford a tank, or the security to keep other poor people from stealing their water, so they buy it in 20 liter jerry cans for about 3 Kenya shilling per container if the seller is honest. That is not always a good assumption.

The marketing of water is a major source of corruption in the capital city. The government supposedly has a monopoly on the movement of water. They do own the pipeline and treatment system. However they cannot police the pipes everywhere, all the time. Water selling companies, some legitimate and others not, tap the main lines to fill their trucks and then sell the water to people who should be getting water through the piping system. Demand from wealthier families is high enough to force up the price for water. This means that these companies can defy the government price control and sell water for more than 3 Kenya shillings on the street as long as they do not get caught. Bribes usually keep the police and other city officials from enforcing the rules. The dual system for getting water to houses works reasonably as long as the supply is high, but in a drought year things can become chaotic, especially in the city's vast slums housing half or more of its population. To date the government has kept things somewhat under control but supply will always be a concern.

Sanitation is another issue. Kibera, one of the largest slums in Africa, sits on the west side of Nairobi straddling the main railway line out of the city to the west. A stream flows right through the slum and people live precariously on either side of the stream and railway. The population of the slum is highly debated. It is a small area of just over 200 hectares and very crowded. The minimum population provided by the government is about 350,000. It could be higher, but any estimates above 500,000 should be taken with a grain of salt. There are no roads through the slum, just alleys. In the heart of the slum the alleys are ditches that you straddle. With a rain the place is muddy and dangerous to walk, and this has nothing to do with thieves; it is just really slippery with a combination of plastic and a frictionless red clay making passage treacherous. Toilets are rare, more common around the edges of the slum than in the center. It has a reputation as the "house of flying toilets", a reference to the habit of defecating into a plastic bag and throwing the bag out the window. A rain washes the sewage down the ditches and into the stream. It is hard to stay clean. Keeping healthy is a challenge, yet people still do[1]. An NGO called Carolina for Kibera established a health center called the Tabitha Clinic in the heart of the slum. It deals with AIDS, malaria and a variety of tropical diseases, but the most common problems all relate to sanitation. Diarrheal diseases like amoebic dysentery, giardia, typhus, typhoid fever, and even cholera, which is thankfully very rare, are a constant concern. Prevention is the primary goal but it is very difficult with the poor water supply and lack of good toilet facilities.

The problems of pastoralism

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[1] See "What Sanitation Means in Nairobi Slums." By Kei Otsuki, Solution Journal Volume 4 Issue 5, October 2013 http://www.thesolutionsjournal.com/node/24010

Outside the cities and the high potential agricultural areas water supply becomes the main concern and sanitation, while still important, recedes. Three quarters of Kenya is populated by pastoral peoples. Their lives are dominated by the need to move for water and fodder. It is a complex dance with a fickle environment. In northern Kenya around the southern end of Lake Turkana the Rendille people have moved their cattle, sheep, goats, donkeys and camels across the harsh windy landscape for centuries. The landscape in this region is harsh and rocky, with volcanic hills and isolated mountains, like the Ndoto Mountains and Mt. Nyiru, which provide places to see across wide distances. Memory is one of the most important resources these people possess. To traverse this landscape keeping in mind the isolated, reliable sources of water is essential. A Rendille elder interviewed by an anthropologist on a hill top with a detailed map was able to trace of 50 years of migration across this land. The old man kept a journal in his mind of grass and shrub growth, water amounts, length of each stay in a particular location, the distance of each move and the time it took. It was a diary of life, good years and bad years all defined by rainfall and fodder. The hills enabled the old man to see rain in the distance, assess the amount and anticipate the resultant feed supply for the animals and time the movement for the extended family group.[2] The length of stay between movements all depended on the needs of the animals and their ability to provide food for the family.

These movements still happen but increased population, immigration of people to the highlands of the Ndoto Mountains and the restrictions of government policy have all changed the lifestyle. Portions of the family, especially mothers and younger children and the very old now stay sedentary in villages with a permanent water source. The animals still move with the men and younger women because it is the only way to keep them fed. This new pattern has lead to overgrazing around the water source and dependence on food from outside. No place in Kenya has remained immune from these changes, though the changes are more extreme closer to the higher population areas.

In southern Kenya the Maasai are the major pastoral group. Their lands straddle the Kenya Tanzania border from the Serengeti and Maasai Mara in the west to Mount Kilimanjaro in the east. To the North their former range extended to what is now Nairobi, whose name derives from the Maasai word for a cold wet place. The Nilotic speaking Maasai people interacted with the Bantu speaking Kikuyu and Kamba groups to their north on a regular basis. They overlapped every dry season when the Maasai brought their animals into the Kamba and Kikuyu lands to graze. This was not historically an antagonistic relationship. Certainly there were tensions between young men at crucial dry season watering spots, but there were also intermarriages, friendships and economic exchanges happening all the time. Then came the colonial era and the creation of fixed borders; instead of relationships determined by rainfall in any given year, suddenly there were antagonisms established by fences and railways. The semi-nomadic Maasai were cut off from their full dry season grazing area, confined now to the fewer permanent watering sites in their drier region. Overgrazing and erosion became more common. So the government, first colonial and then national, in cooperation with international donor agencies, established new watering places using boreholes and diesel powered pumps. At the same time the Kenyan government, run primarily by agricultural peoples from high potential areas, decided

[2] This is based on an article I read while living in Kenya in the 1980s, but I have not located the exact reference. I did use the article "Composition of household herds and Rendille settlement patterns." By Eric Abella Roth and Elliot Fratkin. Nomadic Peoples Number 28, 1991.

that pastoral peoples like the Maasai needed to have fixed boundaries and came up with the idea of group ranches. This essentially overlaid a "private property" system on top of a pastoral system that required constant movement. As this movement stopped new problems surfaced.

Maasai normally live in camps with relatively simple, rapidly constructed huts made of sticks, mud and cattle manure. These huts are made inside a boma, a thorn branch fence made of locally cut thorn bushes and trees. They stay in these settlements seasonally, protecting their animals at night and then moving out daily to graze the animals. The bomas are usually close to a water source. They change bomas when the forage declines. With the group ranch system the bomas don't change, at least not as often. They build within easy walking distance of a borehole or other water source and sometimes stay for years. This has a number of negative impacts on the environment. Manure becomes a problem. It builds up day by day in the boma, getting thicker through time, thick enough that some sell it as fertilizer to wealthier farmers in highland areas. This means that Maasai land exports nutrients from its dry landscape. It also means that when rains arrive the number of parasites in the boma that build up through time have a field day with the animals and people. Deforestation of the thorn tree bush land and savanna becomes an issue and people have to go further to fetch firewood. Finally their animals, especially the sheep and goats now confined to a smaller grazing area, consume everything in a slowly expanding ring around the borehole. It becomes an area of circular desertification defined by the water source.

The story of the Maasai and other pastoral groups is depressing reading. The problem of modernization lies in its denial of ecological understanding and nutrient cycles. The Maasai, Samburu, Rendille and other pastoral groups had an innate though unarticulated understanding of both and developed their culture within these ecological boundaries. The new political reality has forced a transformation and most of that is negative. There is one bright spot in this gloomy picture. Political control, especially centralized political control, often requires citizen ignorance. If you cannot access the right information then you cannot control your own destiny. Some politicians organize their entire careers around capitalizing on the ignorance of their citizens. Because pastoral people live in a diffuse landscape accessing information is difficult and they are easy to manipulate. And then came the cell phone.

Cell phone towers are common in Kenya. Coverage there is better in many ways then coverage in the United States, certainly better than in low population areas in the western US. Kenya never had a good land line phone system. They are too expensive and too resource intensive to establish. Cell phone systems have a distinct advantage. If you can get cell phone towers established on high points at spacing of approximately 10 kilometers you can cover the country. Solar power and batteries can supplement or replace diesel generators to supply electricity for the towers. Once in place the system is accessible by everyone. A Samburu herder on the slopes of Mt. Sabachi can contact the elders in his area from miles away with a simple touch of a few buttons. If he needs help it will come. What does this mean for water?

In pastoral areas of Africa conflict often revolves around water sources and grazing territory, especially if the rains have not been good. Young men from different groups cross paths at water holes, conversations get heated and sometime violence erupts. Politicians can easily push buttons in these situations to manipulate the situation to their advantage, often making a substantial profit from stolen cattle. Now the young men have cell phones. They do not call the politicians, they call the elders. The elders have the cell phone numbers of the elders of the other group. They talk. They argue. Then they come to an understanding and call the young men back with a resolution. It is not a perfect system. It does not always work cleanly and quickly or stop all the violence, but it is locally controlled and the ability of politicians to manipulate the system is minimized. As these new relationships mature the potential to resolve long term water based conflict grows and better management systems are developed. The centralized control diminishes and local systems come to the fore with better ecological and cultural understanding. Even if flawed, the cell phone has added a new dimension to pastoral life that could lead to better systems in the near future.[3]

The Utooni Development Organization[4]

The land of the Kamba speaking people lies in the counties of Machakos, Makueni and Kitui. Here the land is hilly, with the highest points reaching nearly 2000 meters, often steep, and commonly dry. Rainfall patterns in this region that lies between 0 and 3 degrees south latitude and 37 and 39 degree east longitude are complex and often insufficient to produce crops. Because of its location the intertropical convergence zone, the equatorial phenomenon that produces weather in the tropics, passes over the region twice a year, giving two rainy seasons. The long rains occur in March, April and into May. The short rains last from October to early December. However these two 60 day periods of rain are inconsistent, occasionally fail completely, and sometimes do not last long enough to allow a crop to complete its growth cycle. As a result the region has a chronic food deficit, only broken in the rare good season when rains permit growth of maize.

The region is not as consistent as painted in the paragraph above. The topography slopes from high points in Machakos and north-western Makueni, lowers toward Kitui to the north and gradually drops in elevation and gets correspondingly drier as you move south and east toward Kenya's Indian Ocean coast. The upper regions receive 800 to 1200mm of rainfall per year on average while the lowest areas of Kitui and Makueni receive less than 500mm annually. Generally maize requires 600mm of rainfall in one season to guarantee a crop. Only on the hilltops of the upper region in normal or above average seasons are rainfalls consistently sufficient. Yet the Kamba people throughout this region persist in planting maize in hope that they will catch a good rainy season.

In the 1970's Joshua Mukusya, working with the National Christian Council of Kenya (NCCK), was very aware of these dual problems. He grew up near Kola, a town not far from the present border between Machakos and Makueni Counties. As a young boy he was often sent down the hill to fetch water in whatever container he could find then carry it back up hill to his mother. If he spilled a drop on the way he received a vivid reminder of why you should be careful. As he grew he wondered why it is that rain falls on his house and runs off downhill, then later he has to run downhill to fetch it. Why not catch it before it runs away (Mukusya, personal communication July 2011).

[3] Based on conversations around campfires with Mike Rainy and Samburu elders north of Archer's Post at Mt. Sabachi, Samburu County, Kenya in June 2013.

[4] Most of the UDO section is based on my three visits to the region in 2009, 2011 and 2013, spending time building dams, visiting even more sites and conversing with the UDO leaders. All the pictures are mine.

In 1978 Joshua and his wife Rhoda worked with 5 other families and founded a self help group (SHG) they called the Utooni SHG. They wanted to work on issues related to water, agriculture, firewood and trees and local economic development including housing. The centrality of water kept them focused as did the lessons from development failures that Joshua witnessed during his time with NCCK. Through time the self help group, which still functions, grew into the Utooni Development Organization (UDO) that works throughout Machakos and Makueni Counties and has even expanded into Kajiado County among the Maasai. They primarily build sand dams, but they never lost focus on Joshua's original vision of not having to chase water downhill. One look at their compound in Kola tells the story (Figure 2).

Figure 2: The UDO compound's main water storage that holds 220,000 liters. The square tank on the left holds 60,000 liters. The main office building is on the right.

The UDO compound consists of four large buildings made of rock and cement and a covered parking area. It stands on a slope now terraced and has a large garden and lots of trees, which is somewhat unusual for the area. All the buildings have metal roofs and every roof has gutters to collect water. Hardly a drop of rain landing on the roof ever hits the ground; instead water is channeled to a number of water tanks. Five of these tanks are the large black plastic variety, three holding 10,000 liters and two of 5,000 liters. These however are dwarfed by the large cement tank that holds nearly all the runoff from the office building, the covered parking area and two ends of the long narrow buildings where guests stay. It holds 220,000 liters (Figure 2). A smaller cement tank next to it holds an additional 60,000 liters. Joshua calculated that the 320,000 liters of water storage would only be completely filled during a heavy rainy season, but he wanted to catch all the water, and it does. UDO seldom has to buy water, nor do they need to expend extra energy to fetch it. UDO models its own philosophy; make the best use of the resources close to home.

UDO has taken this philosophy to the field. A self help group near the town of Mtito Andei built a catchment system on a large rock outcropping. These rocky outcroppings are primarily hunks of granitic rock very resistant to erosion that were remaining after the surrounding plain eroded. The barren nature of these slopes might be natural or might be a result of past overgrazing, it is impossible to know, but to UDO they became a resource. The Miamba Mitamboni SHG and UDO designed a catchment on the rock outlined by a low rock and cement wall between 15 and 30 cm high depending on natural fluctuations in the rock (See Figure 3 below). The low wall channels rainfall to an outlet pipe at the lowest section of the approximately 3500m^2catchment. This water flows to two 150,000 liter storage tanks. Because there is no forage on the catchment rock animals stay away for the most part and the resulting captured water is quite clean and much lower in salt than water found in nearby streams or wells. It is the preferred water supply for all the families within donkey cart distance

Figure 3: Catchment area of the Miamba Mitamboni SHG. The low cement and rock walls converge at a point behind the shrub in the lower left and feed into a pipe leading to the storage tanks.

of the storage tanks (Figure 4). The members of Miamba Mitamboni SHG sell the water for 3 Kenya Shillings per 20 liters jerry can. This money goes into a group fund to finance group projects like the community garden irrigated by catchment water and a revolving microloan fund available to SHG members.

Figure 4: Miamba Mitamboni water storage tanks with the native acacia bush land in the background.

Though the catchment system is impressive, the available rock that allows their creation is relatively rare. Most of UDO's energy is focused on building sand dams. Joshua Mukusya worked with a man named Ndunda who had built dams with the British in the 1950's. Joshua visited some of these dams with Ndunda and saw that many were filled with sediment, primarily sand. When you dug in the sand behind the dam water was there even in the driest of seasons. The thought came to him at the time, why not build dams intentionally to capture the sand. Within NCCK he had seen literature about sub-surface dams used to slow subsurface flow of water to allow pastoralists to water their animals without the need to dig deeply and lift the water to the animal. The subsurface dams enabled the animals to drink the water directly. This would not work in Machakos very well since the rivers had too steep a slope and the amount of sand trapped would be minimal. By constructing a dam between 1 and 3 meters high they could capture more sand and therefore more water in the pore space between the sand grains. Joshua and the Utooni Development Self Help Group built their first dam in 1978 and it worked.

Figure 5: This sand dam was built in 2009 by the Kitandi Fruit Tree Growers SHG on the Kaiti River in Makuieni County. It was extended one year later to reach its present height. It has a 17.9 meter spillway and holds nearly 11,000 cubic meters of sand and 4,000 cubic meters of water when saturated. Note the strong stand of napier grass on the right stream bank. It is also planted as cuttings on the left bank. (Photo by the author, July 2013)

Sand dams are of necessity bulky structures as seen in Figure 5. They stand across a stream holding a considerable volume of water and sand depending on the height of the dam and the degree of slope in the stream. In order to hold fast they must anchor to the bedrock of the stream. Across the entire width of the stream loose bedding material must be cleared to bedrock, including the sand, which may involve digging through a lot of soil to anchor the wings of the dam. Most dams measure between 1 and 4 meters in height above bedrock and are highly variable in width. Figure 5 shows a typical dam, this one built by the Kitandi Fruit Tree Growers SHG. In general the dams are just less than 2 meters thick at their base and sloping on their downstream side toward the top which is about a meter thick. The uphill side is vertical. The dam in Figure 6 contains approximately 85 cubic meters of cement, sand, water and rock. They are anchored to bedrock using 18mm rebar that extends from the rock to just below the top of the dam. Forms are made after the rebar is secured and the process of building the dam begins.

The sand in the dam, seen in Figure 5, comes naturally as part of the bed load of a stream. Natural erosion moves sand with water flows every rainy season. When the dam slows the movement of water the sand particles, heavier than silt or clay, drop out rather quickly. With more rains, more

Figure 6: A newly constructed sand dam by the Kitito Self Help Group, finished in June 2013. The dam has a 17.5 meter spillway. The 1.4 meter high left wing adds an additional 7.7 meters and the right wing another 6.0 meters. It stands 2.8 meters above bedrock, is 1.8 meters thick at the base, 1.0 meter at the top of the spillway, and 0.68meters at the top of each wing. The entire structure has a volume of approximately 85 cubic meters, built by hand.

sand comes downstream and the dam fills up in consecutive layers. UDO field officers claim that this takes between 1 and 3 years. Early in the process of filling up the sand dam will have some clay and silt, most of which concentrates on the surface of the sand, but this is flushed over the dam in the next rainy season. When fully mature the dam fill is primarily sand. The dam shown in Figure 5 was measured in July of 2013 and found to contain nearly 11,000 cubic meters of sand. Since sand has a porosity of between 35 and 42%, this mean it contains 3800 cubic meters of water at full capacity, which does not include the elevated water levels in the natural water table on both sides of stored sand. The total amount of water available for extraction from this dam could potentially be greater than 10 million liters.

Having water is transforming even if not immediately visible. UDO has documented a number of these changes as has Sahelian Solutions (SASOL) another NGO working on sand dams in the neighboring county of Kitui. The first impact is felt by women. The amount of time they and the rest of their family must walk to fetch water drops. It is not unusual for a woman to cut this time by three hours a day, though the average used by UDO is between one and two hours per day. This shortened distance may allow women to transfer the job of fetching water to other family members, increasing time available to work on the farm, cook, care for children and participate in community activities. Since the water is cleaner, instances of diarrheal disease drop. SASOL has documented an increase in school attendance after sand dams are fully functional (Mutiso et al 2008) primarily because illness drops and nutrition improves. These immediate benefits lead to longer term gains.

The general pattern in rural Kenya is for women to run household activities and men to seek work for cash. Income from farming in semi-arid areas is minimal and seasonally highly inconsistent, so many men seek work in cities. When water is available opportunities change. This is especially true if the household has land a short distance from a sand dam. When walking and measuring sand dams in July of 2013 a number of farmers were seen in close proximity to the stream. A number of men and women were working in small terraced plots preparing and planting vegetable gardens. Their primary crops were sukuma wiki, a vegetable related to collards and kale, tomatoes, onions and Swiss chard, which they call spinach when translating from Kamba. All these are highly marketable, often sold in the early morning and taken to local cities like Wote and Machakos. In these smaller gardens the farmers carry 20 liter jerry cans of water from the sand dam to their plots and water the vegetables growing in slight depressions. Though I did not see this personally, the UDO field officers said that a number of households as far as half a kilometer from the dam and always uphill do the same things around their houses. They often use a donkey to carry up to 4 jerry cans per load with children between 8 and 14 leading the donkey.

Though less common, primarily because level land near the streams is rare, some farmers had installed pumps. Justin, chair of the Mkuta Mwea SHG has a diesel powered pump at the base of a dam in an enhanced natural depression in the river. He pumps to a garden where he raises tomatoes, French beans, Swiss chard, green peppers, sikuma wiki, maize and green gram. Though he uses some to feed his family, most of his product is sold. He does not have to take the crop to market himself. His reputation as a quality farmer is high and those who sell his goods in Wote come to him to get their produce. His pump was paid off completely in the first year of his operation.

Another farmer, chair of the Kitandi Fruit Tree Growers SHG, has a large farm adjacent to the stream with a pump. True to the name, he has planted a lot of fruit trees. When asked if other members also plant fruit trees he said yes, but most grow them near their homes and bring water from the dams to get them started. All of them were using the large nursery on his property to grow the seedling trees for their farms. The species grown include avocado, citrus, mango, guava, papaya, banana and even a macadamia nut. Most of the trees are young, yet to reach their primary production years, but the avocado production was impressive. Also impressive was the quantity of vegetables growing on the farm. These are watered by gravity from two 1000 liter tanks that are filled by the pump. These serve as a reservoir for the water to conserve fuel. A woman the chair hired who had no land of her own, was watering and weeding the vegetables. Most of these were sold in nearby towns.

While the number of vegetables and fruit trees is significant the most common plant grown near the sand dams is napier grass (Figure 5 on the right of the dam), *Pennisetum purpureum*.[5] This is a very deep rooted fodder grass with an ability to spread slowly via rhizomes and stolons, but mostly planted through root cuttings. When established it can stabilize the steep banks of terraces and it does very well on stream banks as well. Its primary purpose is as a fodder grass. The chair of Kitandi Fruit Tree Growers explained that the grass provides cut and carry fodder for lactating cows and goats, extending the milking periods and improving the health of calves, kids and people, especially children. This otherwise

[5] *FAOPennisetum purpureum*: http://www.fao.org/ag/agp/AGPC/doc/gbase/data/Pf000301.HTM

unavailable protein supply is one of the most important benefits of the sand dams. When combined with its erosion control qualities, napier grass is arguably the most important crop of the sand dams.

Another important long term benefit of the sand dams is trees. No one has done more than Patrick Musyimi of the Makuta Mwea SHG who has planted over 10,000 trees and he is still working on his forest. Other than fruit trees, the most commonly planted species in the higher elevation areas of Machakos and Makueni are *Eucalyptus camaldulensis*, *Croton megalocarpus, Grevillea robusta, Warburgia ugandensis and Prunus africanum*, only the last two are Kenyan natives with medicinal properties. In lower, drier areas *Melia volkensii* and *Azadirachta indica* are more important. Most trees need little or no supplemental water after they are established, the trick is getting them started and the sand dam provides the water to enable them to thrive. Through time this will help lead to a reforestation of the region, which is already visible in the near infrared from satellite data (Ryan 2012).

As UDO helped communities build sand dams, other communities both inside and outside the country have expressed interest, including the Maasai in neighboring Kajiado. The Maasai primarily want to improve available water for their animals and sand dams have distinct advantages over boreholes. First, they provide water over a long area, not just at one distinct point, so the damage to the landscape is reduced. Second they are far cheaper than a borehole and are built using primarily local resources. An average sand dam costs around $15,000 excluding labor, sand and rock, all provided by the community SHG doing the building. A borehole costs on average about $75,000. Most local communities can afford neither, so outside assistance is required, but since communities participate in building a sand dam the sense of local ownership in much higher and therefore the sense of responsibility for the outcome is higher. Third, sand dams have no running costs and rarely need repairs. Since starting construction of sand dams in 1978 UDO has built nearly 1500, only 4 have failed. Perhaps the greatest advantage though comes in the impact on vegetation with the higher water table near seasonally dry streams. Riparian vegetation improves through time and this is an important source of dry season fodder for the Maasai. Since they are almost entirely dependent on milk for sustenance any improvement in cattle, goat and sheep production improves things for them. One Maasai made a very simple comment to Arnold, the field officer for Kajiado, “At our sand dam there is no need to queue.”

Thinking big by thinking small

A questions almost always asked by people new to sand dams and the idea of catching water high in a water shed is this; what about the people downstream? Don’t they have less water available because the people upstream are keeping their water? It is a good question and deserves a solid answer. SASOL and UDO have started sorting this out. The starting point is the ecosystem; what does the watershed, the entire area that drains water to the dam or series of dams in a stream really look like? How does water move across this landscape? What did the natural system look like before humans altered the landscape? How did the flow patterns of water change in the altered landscape? Historical information is difficult to find. What we do know is contained in the memories of the oldest community members. Dr. Gideon Mutiso, a co-founder of SASOL and longtime development consultant and academic, interviewed many of the old farmers in Machakos and Kitui, his home area, and captured a piece of this lost information.

The Kitui, Machakos and Makueni region has always been dry, sub-humid to semi-arid. What has changed is the number of trees. It was a near continuous deciduous tropical forest in its higher regions and savanna woodland in the lower reaches. The lower reaches were the home of large mammals like elephant, black and white rhinoceros, numerous antelopes from eland to dik-dik, cape buffalo, giraffe and lions and leopards. Stream flow throughout the region was low but continuous. Rainfall did not rush of the landscape when it fell; instead it hit a vegetated surface, slowed and flowed through the soil and in the water table. Springs were common. They still existed in much of the region even to the end of the 1940s. That is when the dramatic changes really hit. The big game was basically wiped out and confined to the parks. The highlands were deforested, converted to agriculture. The lowlands changed with the loss of browsing game like black rhinos, and acacia/commiphora scrub took over. Rainfall more commonly hit bare soil in the highlands and ran off quickly, carrying soil with it, and failed to reach the water table at all. The water table lowered, springs dried up and streams became ephemeral, widened, with an increased bed load of sand, silt and clay.

The renewed landscape promoted by UDO, SASOL and others seeks to restore a modified original ecology while maintaining a productive agriculture for people. They recognize the need to supply water as a first step, thus the sand dams. They also see the loss of perennial vegetation as a key aspect of degradation, so they promote tree planting and the growing of grasses. They also know that people have to grow crops in a way that reduces or eliminates further damage to the soil. Thus they promote terraces, advocate to no-till and no burn agriculture and push for drought tolerant crops. These changes capture more rainfall and put it back in the ground. A dam captures only a tiny fraction of the water flowing off the landscape. Researches from Vrije University, Amsterdam studied this in a watershed south of Kitui town and calculated a capture of 1-3% of seasonal flow by the dams (Borst et al 2006 and Hut et al 2008). This water is not lost; it is merely slowed and stored for later more controlled release. As the groundwater begins to swell as the sand dams raise the stream level, combined with the terraces and trees slowing surface run off allowing more water to enter the soil, it eventually reaches the spring outlet points. The total amount of water flowing down the river does not change, what really changes is the timing of the flow. Instead of rushing in quick, energetic and damaging bursts, water flows more gently over a longer period both on the surface and underground. When the original underground water profile is restored, the amount of water available down steam at any given time goes up not down. The biggest significant change is that the size of the flood flow drops while the base flow is restored.

Lessons for the west

Note especially that the changes occurring are incremental. It is a series of slow, small, locally controlled and implemented steps that ultimately restores an ecosystem. It is time that we recognize that the big dramatic changes often promoted in the past ultimately did more harm than good. We do not need Kenya to tell us this. Just look at the Colorado River Basin in the United States. We had a water problem in Los Angeles, Las Vegas and Phoenix and built Hoover Dam, Glen Canyon Dam, and a series of slightly smaller dams to solve the water problem. What were the results? The entire Colorado River delta in Mexico died. Mono Lake in California nearly dried up. The Owens River Valley ranches nearly collapsed. All the huge changes made in the watershed changed the entire ecosystem making it more vulnerable to natural changes in climate, to say nothing of longer term less predictable changes due to climate change. There is no large scale solution to the problem of the Colorado Basin that will not result in unintended consequences doing more harm than good. Small changes repeated in multiple locations just might.

To solve the problem of the Colorado we have to start at the top of the watershed. The headwaters of the River lie in the Rocky Mountains of Colorado, Wyoming, Utah and Arizona. These were lands once dominated by multispecies pine and fir forests, extensive grassland meadows and forested rivers. The land was never as rich or deep soiled as the Midwest, or teaming with wildlife like the short-grass prairies, but it did have American bison, elk, mule deer, pronghorn antelope, wolves and mountain lion and perhaps above all beavers. Beavers are the water engineers, the sand dam builders of the animal kingdom. They are the kings of local, small scale water solutions and a pain in the neck to those who want things to always stay the same. Beavers eat trees, build dams, spread out water promote fish habitat and push landscapes to grow new species of trees and shrubs. Above all they slow the rush of water down hill making it do more work as it goes, filling water tables, promoting springs and creating more niches for other life. We no longer manage land that allows for beavers or really for any of the other animals that are listed above. In fact humans really do not like bison or wolves, we tolerate elk and deer and beavers we would just like to go away. What would the Colorado look like if we decided to accept beavers again?

It is highly unlikely that we will let the beavers back. It is also highly unlikely that we will let the bison dominate the great basin again. Our cattle are too important. What is more likely is that we change our management of the Rocky Mountain highlands. In the chapter on The Problem of Brittle Landscapes the work of Alan Savory and Holistic Management played the central role. This system is not a universal blueprint for an entire ecosystem; it is a set of guidelines implemented on a single ranch scale that can improve ranch environments as they also improve ranch economics. The environment and economy do not have to operate as oppositional forces. They can operate in concert. The examples provided in Holistic Management are analogous to the examples of success found in the farms now relying on sand dams for their water. Small, slow, local solutions work and when the number of small slow and local solutions spread across a watershed at any scale, the ecosystem of that watershed heals.

A few more examples will help. Australia took the record for the most rapid human demolition of a continent from the Americans. This shameful legacy was illustrated graphically in a documentary showing two large caterpillar bulldozers tied together with a thick chain dragging it across a landscape and tearing out eucalyptus and acacia trees by the roots to prepare the land for grasses and ranches. Needless to say the results were not pretty. Massive erosion, degraded streams, failed grasses and desertification were the end result. Australia has some of the oldest, most weathered soils on the planet. They are nutrient poor, often acidic and commonly low in organic matter. Tearing out the trees roots did not help with that problem. With the trees gone water flowed directly downslope, perpendicular to contour lines, creating gullies as it went. When the rains stopped the unprotected soil formed a nearly impermeable cap preventing infiltration of water so the next time it rained the runoff was even worse. It was nearly impossible to get grasses established in these conditions.

The problem did not go unnoticed. P.A. Yeomans saw the problem and came up with a solution during the 1950s (Yeomans 2008). The answer lay in addressing both water flow and soil permeability at the same time. To accomplish this Yeomans created a new style deep chisel plow. When we think of plows our minds often picture the smooth elegant curve of the moldboard plow that turns over 15 to 30 cm of soil at a pass, flipping the sod upside down. The Yeomans plow is different. It is designed to go much deeper, 50 to 75 cm, creating a slot, opening the soil allowing water to penetrate, but minimizing overall disturbance. Yeomans saw capping and compaction as the chief problems preventing water penetration. He also realized that you had to plow nearly perpendicular to the direction of flow, but direct any surface flow away from gullies. He called this keyline plowing. A keyline is the contour line that passes through the steepest slope on a gully or stream on a hillside. Above this point the percent slope declines and below it all slopes decline as well. This keyline contour defines how all plow lines are determined on the slope; they are made parallel to the keyline[6]. This helps move water from its natural tendency to concentrate in a low valley toward the drier soils of a convex slope on a ridge. Water constantly soaks in along these plow lines, but any surplus moves away from rather than toward the points of maximum erosion. By having a series of these lines on a slope, the distance between these lines determined by the degree of slope and permeability of the soil surface, starting from the keyline and working up or downhill, you create the conditions needed to establish grasses. Any surplus water can then be directed to a series of ponds on a hillside to store the water and release it slowly to another keyline as illustrated in Figure 7. Like sand dams and terraces, or beavers and holistic management, these changes in system conditions when done repeatedly change the nature of a watershed.

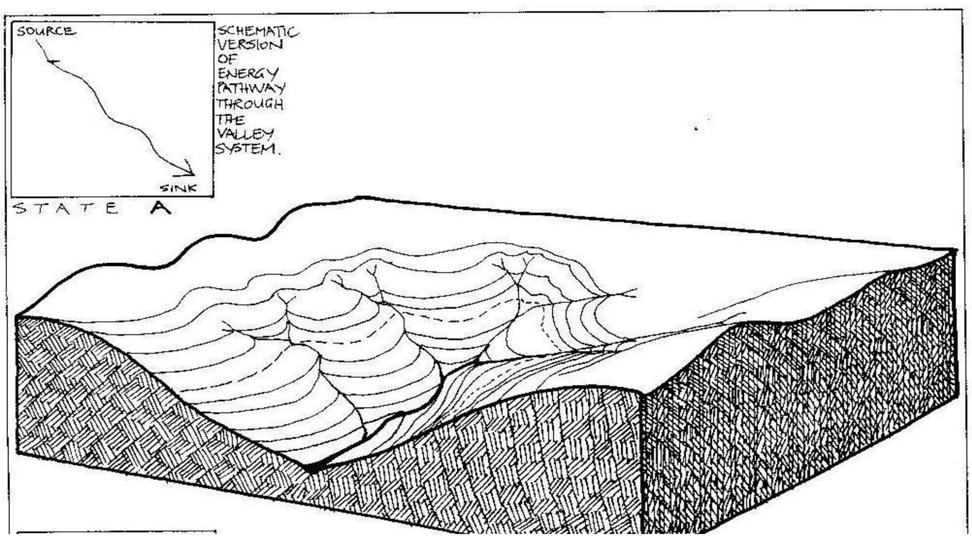

Figure 7a: Watershed drainage pattern on a degraded landscape. From Mollison (1988)

The goal of keyline plowing is enhanced soil fertility through increases in soil organic matter via the roots of plants and surface organic deposition and subsequent reduction in soil bulk density. The soil becomes the main water holding agent on the landscape. The longer the soil retains water the better production is on the land and ultimately the more evenly distributed is the flow in a stream throughout the year. The main way water enters a stream should occur through subsurface flow and springs, not surface runoff. Keyline was developed to make that happen.

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[6] For more detail on this see http://www.yeomansplow.com.au/yeomans-keyline-system.htm

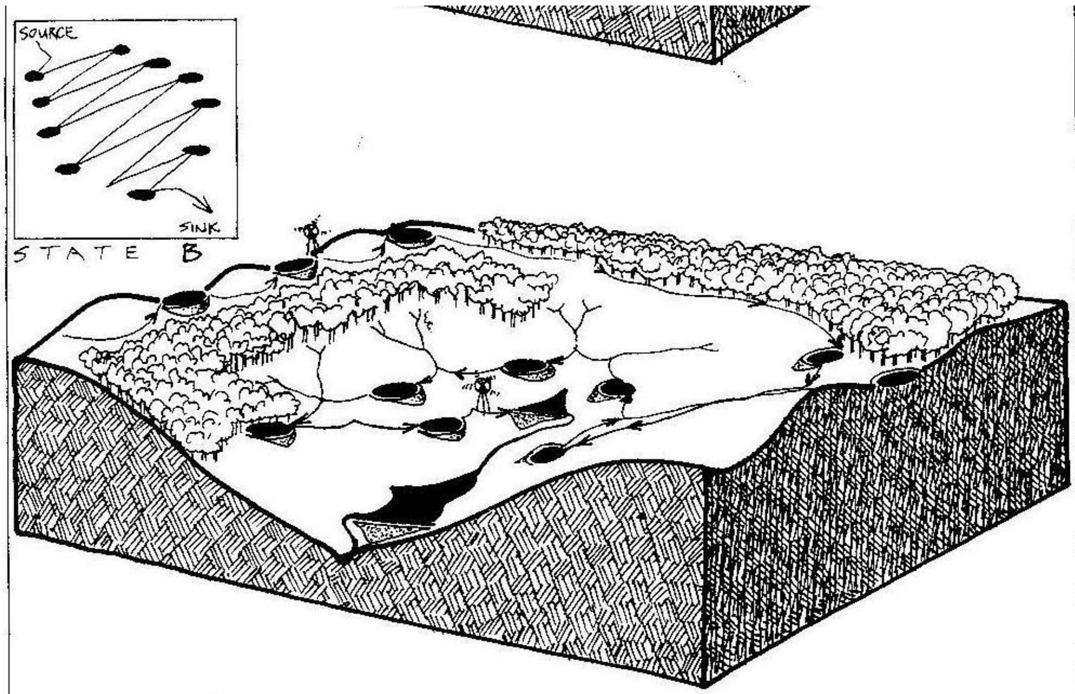

FIGURE 2.1
DESIGNING TO CATCH AND STORE ENERGY.
The designer s work is to set up useful energy storages in a landscape or building (proceeding from State A to State B). Such storages, available for increasing yields, are called resources.

Figure 7b: Managing water on landscapes, slowing flow. From Mollison (1988)

Sepp Holzer had a similar idea, with a completely different implementation method, in the foothills of the Alps in Austria. Holzer farms steep, commonly forested slopes between 1100 and 1500 meters in elevation. In this ecosystem rainfall is not the problem, but the distribution of moisture across the landscape can cause difficulties. Steep south facing slopes are hotter and drier. Valleys and north slopes are cooler and sometimes overly moist. By moving water slowly downhill across the slope to a series of ponds and small wetlands, Holzer increases moisture available to his perennial and annual crops without having a negative effect on the natural streams through his property. In fact, the ponds and wetlands help moderate the microclimate where they are found in such a way that plants normally incapable of surviving at this altitude find a niche to thrive (Holzer 2010). Holzer's work deserves more attention than this brief mention because it is an integrated, systems approach to farming on a hillside landscape in a way that improves the quality of the land rather than extracting from the land, but it is outside the scope of this chapter.

One last example firms up this approach to water management: Geoff Lawton is a permaculture practitioner from Australia who went to Jordan in an area not far from the Dead Sea to advise on an agricultural project. The land at this site is relatively flat, very dry and hot with salty soils. It is not a place that would serve as anyone's first choice for a farm. The group Lawton worked with had 10 hectares of land. There were some nearby farms, but most of the land was used for grazing goats. The animals ate most of the available vegetation and erosion was a problem. Even so Lawton came up with a plan that started with making swales on the contour. His goal was to prevent any loss of water on the property and if possible even catch water flowing onto the land from up slope. He also recognized that the dry, hot air would quickly evaporate any water that fell so he began collecting any source of organic material he could find to serve as mulch. Surrounding farms commonly burned their organic matter every year to prepare fields, so Lawton bought this and used it on his soil, covering it to a depth of 20 inches. Then he planted trees; dates palms formed the high canopy, figs and citrus a lower canopy, and other crops underneath. All were planted through the mulch into what was relatively humid soil protected by the surface organic matter. The humidity and organic matter produced something people did not expect, mushrooms. Saprophytic mushrooms required organic material for food and humidity for moisture and the mulch met both needs. The fungal mycelium provided an unexpected benefit for the crops, they tied up the salt in a way that limited its impact on the plants and they grew faster than expected. Figs started producing in their first year.

The whole project created something of an internet phenomenon when the video “Greening the Desert” was put on YouTube. In turns out that while the permaculture ideas practiced really do work, the cultural aspects of the project made it much harder to maintain and replicate than expected. Unlike the Kamba in Kenya, Yeomans in Australia or Sepp Holzer in Austria, the Bedouin culture of Jordan in this area was not ready for an agricultural project. Without the continuous input of outside energy in the form of Geoff Lawton the project could not sustain itself. This will not always be the case, but conditions have to be right for innovation to catch. In this case the cultural conditions were wrong. This may change through time but it is a tale that illustrates the human factor involved. We are after all a part of the ecosystem. We need willingness to change ourselves before anything else can change in an environment.

Climate change, water supply and our response

Uncertainty. As the reality of climate change stares us in the face there is only one thing that we know; we really do not know that much. What we have are models, very complex models that are able to crunch a seemingly impossible amount of information and come up with projections. As climate scientists like James Hanson (2010), a paleoclimatologist, explain, what they are doing is taking actual data from the past and building a system that accurately follows those trend lines established from data as far back as they can push it to get projections for the future as conditions change with increased CO_2 and other carbon forcing gases in the atmosphere. The outlook is particularly bleak if we continue burning fossil fuels at the present rate for 25 years. We still have a good shot to reduce the level of damage to the planet if we act now with urgency.

A lot of the problem lies with water. Water is our major storage and mover of energy on the planet. As oceans slowly warm to greater depths and air temperature warm as well, the air holds more water vapor. In the heated air it begins to follow slightly adapted patterns to what the world’s ecosystems have evolved to expect. Rains become less frequent but heavier in many places. In other places, more rarely, rains become more frequent as well. This provides temporary advantages to pests like the pine beetles in the western US, making ecosystems more vulnerable to collapse. The results are major fires as recently seen in Arizona, Colorado and New South Wales in Australia, typhoons like Haiyan in the Philippines, drought in Zimbabwe, and the list could go on and on. We do not really know what is going to happen, yet we do know that the planet sits on a precipice. How do we respond?

The answer does not lie in the projections of the scientists, or the denial of reality among global and local politicians. The answer is not one global strategy. The first step is simple; we have to recognize the reality of the problem we face and then develop strategies to respond locally, and all these strategies might have similar components but they must modify according to the ecological conditions of a particular place. What are the abiotic factors of the place you live? What is the present climate? How has it shifted in the last decades? How does rainfall come? Has this changed through time? What are the runoff patterns on your landscape? Where are the most vulnerable places? What needs to happen to slow water down? What type of water supply do you have? Do you control the water supply to your household? What makes it vulnerable? How are crops grown in your area? If rainfall decreases what needs to be done to still get a crop to grow? If rainfall increases, what needs to happen to reduce erosion and keep field moist but not waterlogged? The list of questions can keep growing but it is what we need to ask ourselves. We have to stop contributing climate forcing gases to the atmosphere and we have to adapt to the changes that are already inevitable.

Changes to the hydrologic cycle are arguably the most important aspect of climate change. The centrality of water to the productivity of the planet is unarguable. How we respond to climate change must deal with the changes coming in the hydrologic cycle. We cannot be sustainable if we don't figure out how to make these changes. The examples given in this chapter are just a few of the many possibilities. Now we have to adapt these or find new ways to respond in whatever ecosystem we happen to find ourselves.

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