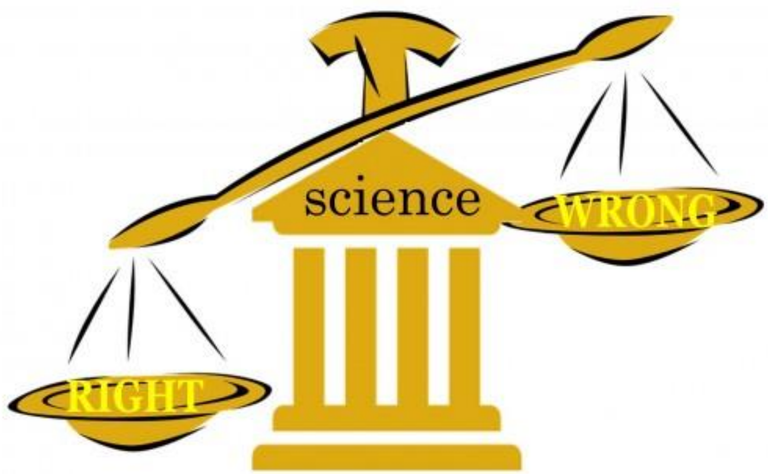
ETHICS:

The Role of Ethics in Environmental Science



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1. Introduction

Ethics is the study of moral behavior and the theoretical treatment of those concepts (Broad 1985). The discussion of ethics began during ancient Greece with philosophers like Aristotle, Socrates, and Plato. They had a desire to define what was good and evil and set a framework for how society and its people should behave (Bourke 1968). Ethics is still a heavily debated topic today, and as science continues to advance at a rapid pace, there will continue to be discussions surrounding ethics. In November of 2018, Chinese scientist He Jiankui announced that he successfully used CRISPR (clustered regularly interspaced short palindromic repeats) to create the first genetically modified human babies - both of whom were born that month (Kolata et al. 2018). The goal of Jiankui's experiment was to alter a gene in the embryos before implantation to make them resistant to HIV. This is an incredibly controversial issue as many people worry that this technology has the potential to be abused. People fear that babies will be engineered for traits like eye color, skin color, athleticism, and intelligence. There is also a concern over the safety of these procedures since no one knows the long-term effects of gene editing in humans. For example, new research shows that Jiankui might have accidentally shortened the lifespan of these two girls(Weintraub 2019). This controversial topic is a great example of the importance of ethics discussion and training for all scientists.

Ethics and philosophy are central topics in majors and subjects surrounding the liberal arts. However, ethics classes are rarely seen in disciplines like environmental science. Even though it is not required by the curriculum for environmental science majors at Montana State University, ethics plays a huge role in all aspects of science careers: government jobs, research, nonprofits, and private organizations. Science influences economics, culture, and politics, and it is important to establish the way scientists should conduct themselves and their research. Without this baseline code of conduct, there is no way to ensure that the science being published is accurate. Distrust in science has only been getting worse, and this is mostly attributed to people's desire to uphold their political beliefs in the very tense political atmosphere the country has seen in the last few decades (Kraft et al. 2015). As environmental issues become more urgent, there has been a call for scientists to step out of their research bubble and become advocates.

As graduating seniors from the Land Resources and Environmental Science (LRES) department at Montana State University, we explore how ethics impacts us as environmental scientists by applying ethics to varying topics of interest. These include issues like climate change, fire management, sustainability in arid regions, mining, food production, energy, and water conservation. It is our hope that by researching ethics in each of our areas of interest, we will leave MSU with concrete knowledge of how to enter the workforce as environmental scientists aware of our ethical duties.

The Merging of Science with Society

It is widely practiced that scientists remain skeptical about their research to avoid believing in a falsehood. However, sometimes moral questions cannot wait for proof or a consensus when immediate action is necessary (Briggle 2012). The 21st century has been marked by unprecedented environmental change. There is universal concern about the impacts of climate change, land conversion, growing populations, food production, and many other anthropogenic influences on the environment. This new era of change has caused many scientists to abandon their main role as a researcher and expand their job to include advocacy. As we continue to approach a point of no return, scientists from all over the world have come together to study human impacts on the environment and develop ways to reverse or mitigate those changes. Because of these extraordinary alterations to our planet within the last 100 years, we believe that ethics plays a larger role in science today than it has in all of human history.

Summary

In the following chapters, we will introduce various issues or topics of interest related to environmental science and how ethics applies. We look at these issues on both local and global scales. In Chapter 2, we focus on how climate change is altering the coral reef ecosystem as well as the ethical implications of this changing system and its impacts on humans. We discuss sustainability of arid regions in Chapter 3, particularly how limited water resources in the future will affect the people living there and how to ethically manage and allocate water. Sticking with the theme of a changing world, Chapter 4 dives into fire management and how to deal with the increasing number of wildfires caused by climate change. Fire can harm people's lives and property, and ethical management of fires is becoming crucial in areas susceptible to fire damage. In Chapter 5, we review the management and impacts of mining on a global and national scale. We look at important ethical questions like the regulations and laws behind mining in the U.S. versus other nations. Food production is the topic of Chapter 6, where we consider the ethical implications of food production, particularly how we are going to meet growing food demands as the global population continues to rise. In Chapter 7, students investigated the impacts of cancer-causing glyphosates in common herbicides such as Round-Up®. In Chapter 8, we explore different sources of renewable energy while reflecting on the impacts of climate change and the ethics behind switching to sustainable sources responsibly. And finally, in Chapter 9, we tackle arguably one of the most pressing issues in our world today: water availability. We examine the ways countries all over the world struggle for safe and affordable access to clean freshwater sources and how the changing climate will only make matters worse. We also look at possible ethical solutions to ensure that everyone has clean and accessible water in a world where the global demand for water is increasing.

These compiled papers aim to address the ethics behind many important environmental issues and how us as soon-to-be environmental scientists are going to deal with these ethical questions. It is our hope to inform the audience of the complexity behind these issues and provide them with the ability to discuss the many ways that ethics plays an important role in science.

2. Coral Reefs

Maddie Lockner, Jenna Aholt & Caitriauna Olson

Introduction

At this point most people have heard about the threatened status of coral reefs across the world following climate change and certain human activities. What is less heard of or widely known is what is being done to fix it, and who is paying for it. Who should pay for it? For the purpose of this paper, we have chosen to focus on coral reefs within the US, particularly Hawai'i, which have suffered widespread bleaching and mortality due to the rising temperatures. The Fourth National Climate Assessment (NCA4) predicts that the reefs will continue to be threatened by rising temperatures and ocean acidification and will experience annual bleaching events by 2040 (Hawaii's Coral… 2019).

What is Coral Bleaching and Why Should We Care?

Coral is an animal from the phylum Cnidaria and live in a symbiosis with zooxanthellae, a photosynthetic alga. Simply put, the zooxanthellae feed the coral while gaining protection and other nutrients in exchange. When coral bleach, the zooxanthellae dies and are expelled from the tissues, leaving the coral to starve (Castro and Huber 2016). Coral can recover from a bleaching event if conditions return to normal and given enough time. However, if the stresses are severe enough or maintained over a longer period, the coral dies (Castro and Huber 2016).

Reef dieback has ecological, social and economical impacts since other than being one of the most diverse ecosystems on earth and supporting thousands of species, coral reefs provides jobs and recreation opportunities. Fishermen rely on the reefs to support their families (Hawai'i's Coral... 2019).

Who is Using the Reefs and Who is Repairing it?

Currently, the Hawai'i Division of Aquatic Resources (DAR) runs a coral restoration nursery to mitigate human impacts on Hawai'ian coral reefs. The nursery grows indigenous coral species in an ex-situ environment and then plants the nursery-grown coral at damaged sites to restore valuable habitat. The nursery could work as a form of mitigation bank "where those responsible for loss of coral cover could pay for the damages by buying coral credits" (Hawaii's Coral... 2019). But there is a problem with this approach. If a boat damages the reef by grounding, it is easy in theory to find the guilty party, but what if the damage is caused by the effects of collective use such as global warming? Global warming is the result of the collective use of resources by earth's population together, each country contributing different amounts depending on development and population, so we cannot point a finger at a single responsible individual to pay for it. In addition, with global warming comes ocean acidification through the ocean's absorption of CO_2 which could lead to additional problems for the coral (Kleypas and Yates 2009). The majority of coral, and many other marine animals, have an exoskeleton built of calcium. When the water becomes more acidic, the calcium dissolves and prevent the normal development of coral and other species (Figure 2.1) (Kleypas and Yates 2009).

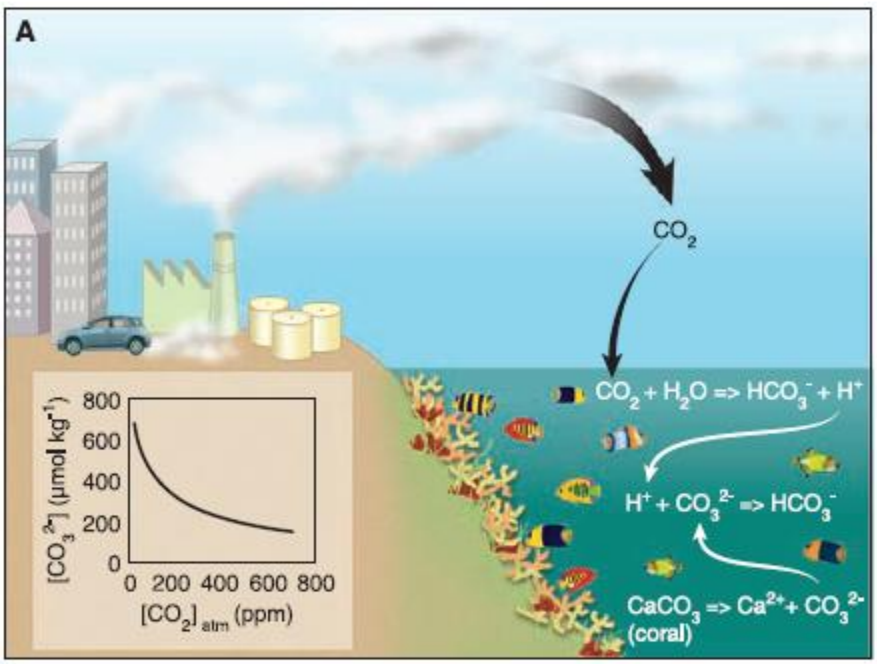


Figure 2.1 (Hoeg-Guldberg et al. ,2007) Linkages between the buildup of atmospheric CO2 and the slowing of coral calcification due to ocean acidification.

Other Sources of Damage and Ethical Implications

In addition to global warming, human activity can damage coral reefs. Thousands of tourists visit Hawai'i every year to snorkel around the reefs, and a direct link has been shown between coral mortality and certain ingredients commonly found in sunscreen. It is estimated that "6,000 and 14,000 tons of sunscreen—the equivalent of 25 to 60 million bottles—wash off of snorkelers and swimmers into coral reef environments each year" (Sentman 2019). Imagine what an impact this could have on the reefs. Hawai'i is currently trying to mitigate this issue by selling coral safe sunscreen. In fact, regulations include bans or restrictions of sunscreens containing oxybenzone and octinoxate which have been found to be harmful to coral health (Raffa 2018).

Right now DAR funds their projects by applying for a competitive grant from NOAA's coral reef management grant program, which provokes the question "should they have to compete to restore coral?" Is it ethically right to leave the responsibility of restoring our reefs to a few independent groups when there are so many users benefitting from the reefs? Maybe we should consider a more permanent source of funding for such projects.

There are many ecological processes that depend on the coral reefs but because of the massive amounts of fish in the reefs, they also provide a base for the fishing economy for many coastal areas. The overfishing of reefs causes collapses in ecosystems due to a change in the structure of the food web (Valentine 2005). But even if the fishing is not always harming the reefs, the reef dieback can have a major impact on commercial fishing. Although there does not seem to be any current effects on the fisheries of coral reefs, Graham et al. 2007 states that there may be a lag effect. The lag effects suggest that after the initial death of the ecosystem it may take time for the individual species to feel the repercussions. They estimated that about 5 years is all that is needed before the full effect of coral bleaching on reef fisheries is realized (Graham et al. 2007).

The ocean is a solar energy collector that covers over 70% of the earth's surface (Dahlman 2018). Increased temperatures in the ocean over the past 50 years accounts for roughly 90% of all the warming that has occurred globally (Glusac 2018). A study in 2017 by the United Nations Environment Program concludes approximately 80% of marine pollution comes from wastewater, sediment settlement, and nutrient runoff from land-based streams (Grimsditch 2019).

Why Coral Reefs are Important

Although coral reefs are extremely important to tourism and economics in the United States, they are also very important to marine life. Even though they only make up about 1% of the earth's surface, coral reefs are essential to about ¼ of all marine life (McIntyre 2010). They are a vital part of keeping our oceans and air clean because of their ability to cycle nutrients and provide food, shelter and breeding grounds (Graham 2007). The collapse of the coral reefs are not anything new, in fact the first report of concern came up in the 1960's when a non-native species of sea star had a massive population explosion in the coral reefs (McIntyre 2010). One of the biggest reasons that it was not as publicized as the terrestrial loss of biodiversity for many years was because of how little was known about the biodiversity of the reefs (McIntyre 2010). Approximately one third of reef building corals are currently at an elevated risk of extinction due to climate change. The rate of extinction is increasing faster than any terrestrial species and is being observed all over the world.

Trophic levels in the reef

Coral reefs have great diversity that stretches across the entire ocean. It all starts with the first trophic level that is made up of producers and autotrophs. These are vital to the ecosystem because they have the ability to produce their own energy and nutrients which is usually through photosynthesis or chemosynthesis. In the coral reefs, the primary producers consist of blue-green algae, phytoplankton, zooxanthellae, seagrass, and brown algae.

The producers are a food source for the next trophic level that are the consumers. With many kinds of consumers, the ones that feed on producers, also known as herbivores, are what is called the primary consumer. The secondary consumers eat the primary consumers and are usually called carnivores or predators. The last category of consumers are the tertiary consumers that are usually carnivores that eat other carnivores. Some of those intermediate consumers consist of animals such as the sergeant major, flaming tongue snail, bar jack, grouper, Caribbean lobster, bicolor damselfish, polychaete worm, cushion sea star, and southern stingray. But the top predator in most coral reef systems is the blacktip reef shark. The last trophic level that is vital to all ecosystems are the decomposers. The decomposers help to recycle all the nutrients and energy through the food system. They break down dead organic material and return the nutrients into the sediment. Then the producers use those nutrients and restart the cycle. The decomposers in coral reefs are the polychaete worm and the queen conch (Brown 2012).

What will happen to the plants and animals?

When coral reefs die, most of the animals that lived there must move and find a new home. Scientists estimate that there are about 4,000 species of fish and 800 species of hard corals that live in coral reefs alone. They also estimate that there may be another 1 to 8 million undiscovered species of organisms living in and around reefs (Reaka-Kudla 1997). If the coral reefs die off then most likely, most of those populations will die. They will either die from starvation or lack of shelter which makes them more susceptible to predators. While predators may benefit from this, it may only be for a short time since the populations of their prey will rapidly decrease with no way of being replenished. Although there are many species that are affected by dying coral, one example of a species that is directly affected is the Butterfly fish. They live in the coral reefs for their entire lives and feed exclusively on coral polyps. They are very important for this ecosystem because they feed on algae that can smother the coral if it goes unchecked (Pratchett 2004). So even if the coral returns in the future, they will not be able to be as strong if the butterfly fish populations are not present.

After the current producers and intermediate consumers have either moved or died off, the larger animals will start to suffer cascading effects. When animals like the angelfish, who feed on smaller animals like the sea slug, run out of food they also have to move or adapt to survive. Once the coral reefs die, the effects will go on to drastically impact many other species and eventually escalate up to reef sharks. If the reef shark populations are altered, they can affect many other ecosystems and population dynamics since they travel all over the ocean. With the lack of breeding areas, some animals that specialize in laying their eggs in the reef will not have a place to spawn which could cause a lack of new populations and a possible extinction of the animals in that reef (Munday 2009).

What we can still learn from coral reefs

Because the coral reefs are one of the most diverse ecosystems on our planet, we are still trying to explore all that they have to offer. There are some studies being done about how the sea slugs could potentially be linked to help cure cancer (Sethi 1970). The sea slug is born in the coral reef and relies on it for food and shelter for its entire life. This one example shows how much we still have to learn from our marine ecosystems and how much we stand to lose without them.

Pollution and Local Implications

Coral reefs have global economic and ecological importance, attracting tourism and providing habitat for a diversity of marine life. Within the U.S. territory the coral reefs are under threat, particularly the coral reefs in the Pacific Ocean surrounding the Islands of Hawai'i. Coral reefs play an important role in Hawai'i's culture as well as their agricultural management considerations. They also affect the political and demographic decisions of water rights, land use, and land ownership. Majority of the coral reefs in the United States are located in the northwestern region of the Hawai'ian Islands, extending up to 1,500 miles across the main-island, small islands, and atolls (America's Coral… 2019). There are 410,000 acres of coral reefs surrounding the islands of Hawai'i (A Living Reef… 2004). Coral reefs also shelter coastal shores from impactful storms that could erode the soil bed. The coral reefs surrounding Hawai'i vary in depth all the way to fifty meters below the surface. Thus, within this area of Hawai'i reef-building does not typically exceed 50 meters depth, where coral accretion is interrupted by bio-erosion (Grigg 2006).

Silent Spring by Rachel Carson put into perspective the influence society has on ecology at a large scale. This book sparked an uproar as it helped draw attention to the lack of environmental regulations that led to the potential decline of human health. Environmental protective agencies were created to monitor, maintain, and enforce regulations on all associations of the disposal of waste, by-products, and development of land. The historic-cultural belief of 'out of sight, out of mind' led to the increasing levels of pollutants in natural water resources. This ecological degradation was not apparent to civilians until marine ecosystems showed a decrease in species biodiversity.

Pollutants at the local level pose a threat to the marine ecosystems. Stream pollutants on the islands include nutrient runoff by agricultural practices, sediment settlement, urban sewage leakage, and chemical composition of daily household items. In addition to oceanic pollutants on the global scale, from drilling and mining waste dumping, warming currents in the ocean leads to the attraction of bacteria that increase the breakdown of coral adding to the bleaching effect (Leggat et al. 2019). Pollution adds to the damage by promoting the growth of macroalgae, seaweed, throwing the system out of balance (Grimsditch 019). According to the World Resource Institute, approximately 60% of the world's reefs are under threat from local stressors, such as fishing and land-based pollution. When local threats to reefs are factored in with thermal stress, the proportion of threatened reefs rises to 75% (Kushner 2012, Coral Reef Ecosystems… 2019).

An example of wastewater pollution was documented between 1970 and 1995 when two sewer outfalls discharged raw sewage into the ocean from the Honolulu watershed. This had a serious but localized impact on shallow reef corals less than 10 meters deep. After 1977, treatment was upgraded and outfalls were improved to no longer impact coral reefs (Grigg et al. 1995).

Historic Governmental Regulations

Over the past century, protective agencies like the Environmental Protection Agency (EPA), and the National Oceanic and Atmospheric Administration (NOAA) were created with the objective of maintaining ecosystem health. In hopes of protecting marine ecosystem assets, the United States Coral Reef Task Force (CRTF) was created to focus primarily on marine health.

The diverse ecosystem of a coral reef provides people with food, medicine, and revenue (Coral Reef… 2019). Coral Reefs have an economic value in the Pacific Ocean under the US Protection projected to be $9-10 billion, generating a profit of $100 million annually from tourism (America's… 2018). Other economic assets of coral reefs are the fish. Local fishermen use these 'hotspots' to support their family businesses, strengthening the ties between their cultural practices and surrounding environmental systems.

Over a century ago, President Roosevelt recognized the islands, atolls, and reefs around Hawai'i in 1909, and created the Hawai'ian Islands National Wildlife Refuge. The first conservation district was established in 1967 in Hanauma Bay, with the goal of decreasing fishing pressure on marine life populations in the surrounding area (A Living Reef… 2004).

A rise in pollution awareness in water and food sources for humans and animals alike created an uproar of concern for public safety. The United States Senate signed the Clean Water Restoration Act of 1966 to clean up water resources from pollution (The Clean Waters Restoration Act Signed into Law, 2019). This led to the development of the Clean Water Act of 1972 which is covering a wider range of water resources and pollution sources. President Nixon established the EPA in 1970 with the purpose of lowering pollutants that pose a threat to human health. Since then the EPA has been working for a cleaner, healthier environment while promoting public safety. The Ocean Dumping Act of 1975 regulated the dumping of industrial waste into the ocean, material that would unreasonably degrade or endanger human health. By

1988 the Ocean Dumping Ban was established to increase restrictions on waste dumping and set a deadline of 1991 to find alternative methods of handling waste (What EPA… 2019).

In 1998, President Clinton established the Coral Reef Task Force (CRTF) to protect and conserve coral reefs. The CRTF is responsible for mapping and monitoring U.S. coral reefs; researching the causes of coral reef degradation including pollution and overfishing and finding solutions to these problems; and promoting conservation and the sustainable use of coral reefs (Protecting Coral Reefs… 2019). The creation of the CRTF laid the groundwork for the Coral Reef Conservation Act of 2000. This included other Executive Orders such as the Northwestern Hawai'ian Islands Coral Reef Reserve, Northwestern Hawai'ian Island Coral Reef Ecosystem Reserve, Final Northwestern Hawai'ian Islands Coral Reef Ecosystem Reserve, and Coral Reef Protection (16 USC Ch.83: Coral Reef Conservation, 2019). These acts are enforced by the CRTF under U.S. jurisdiction.

In recognition of the need to protect the ocean's water from pollutants, the Coral Reef Conservation Act of 2000, set aside 84 million acres of the ocean floor around the Hawai'ian islands. The largest conservation area established in the United States to date, enlarging the jurisdiction boundaries for CRTF.

Moderating Laws on Civilians, Tourists, and Companies

Federal and local regulations regarding coral have been implemented in hopes of reducing major water pollution. On the federal scale, the EPA continues to work through the Executive Order 13089 which entrusts the Clean Water Act and Coral Reefs, U.S. Coral Task Force, and the International Coral Reef Initiative (America's Coral Reefs, 2018) with clean up and monitoring of coral reefs. On the local scale the state of Hawai'i, states it is unlawful to harm, damage, sell, or remove any species of coral in Hawai'i without authorization from the Division of Aquatic Resources (Coral and Live Rock Rules of Hawai'i, 2014).

A Bill in Action

As of August 2019, the Coral Reef Conservation Act of 2000 was brought before Congress to add Restoration Resilient Reefs Act of 2019 for federal and non-federally recognized coral reefs to be enforced by Coral Reef Task Force. This bill is progressing through the system. Elements summarized from the Act were statements of purpose to include current geological maps and problems affecting coral reefs today. The action plan is to submit appropriate detailed plans annually to respective congressional committees. Mandated reports to Congress will be used to review all activities that had happened in the previous year including if the proposed plan was followed, statement of funding, and plans for next year. Activities are to incorporate additional appropriate laws within the United States jurisdiction if needed. Proposed funding for restoration of the United States Coral Reef is $29 million for first-year progressing to $35 million for the fifth year through grants, partnerships, and donations. Proposed federal partnerships include the National Ocean Service of the National Oceanic and Atmospheric Administration, National Park Services, United States Fish and Wildlife Services, and the Office of Insular Affairs of the Interior. These partners will be responsible to monitor coral reefs and determine if a state of emergency has occurred (S.2429- Restoring Resilient Reefs Act of 2019).

Proposed Solution

Since we can’t hold a single party responsible for global warming and ocean acidification, maybe we can focus on the heavy users we have identified. One way might be to charge hotels located near the reefs and companies renting out snorkeling gear a mandatory fee that would go directly towards a restoration fund, since these are a few examples of sources with a negative impact on the reefs. In the end the efforts would feed back into the businesses investing in the restoration fund, a greater number of healthy corals draws more tourists and customers that would utilize these businesses. Coral reefs are important ecosystems that have, as we have discussed in this paper, widespread rippling effects on nature and our society. It’s not sustainable when we are so many benefitting users to have a few groups of enthusiasts, in addition to the clean-up regulations that have been put in place, competing for funding to restore this system when the median project cost for this type of restoration could reach about $400,000/ha and range all the way up to $4,000,000/ha to add substrate and build an artificial reef (Bayraktarov 2019).

Conclusion

The world might be more aware of various effects of global warming, and an increased amount of regulations designed to preserve or protect the environment are put in place today compared to 100 years ago, but how quickly will we be able to see the effects of those efforts?

And how long could systems such as coral reefs survive while waiting for an “improved” environment? At some point, maybe it would make more sense to help the coral reef evolve in pace with the climate. As of now, temperatures are rising too quickly for coral to be able to keep up (Hoegh-Guldberg et al. 2007.) and even if we took every action to stop global warming, it would take a long time to halt and reverse it. But there are people who are already working at “speeding up evolution” of coral. Dr Ruth Gates at The University of Hawai'i dedicated her life to saving coral, and her lab is continuing their research in her name after her passing in 2018. The lab is focusing on biological traits “that drive the differences in performance among corals and reefs” and is actively breeding and developing what they call “super coral”. This is done by collecting zygotes, or coral babies, from a selected few individuals that survived a bleaching event next to coral that did not (Gates Lab 2019.). This might be an alternative and perhaps more time efficient approach to save the reefs.

What is happening to coral reefs is an excellent demonstration of a fundamental concept of global warming. The things we do and the resources we use have an effect, it might not be in our direct field of vision. Richer countries are able to afford more resources, such as oil and metals to mention a few, but the effects of extracting these resources might be most severe outside the borders of the rich country. Usually a developing poor country that lacks the environmental regulations that are put in place in richer countries, simply because they cannot afford to follow them which usually leads to suffering for animal life, humans and nature in the poor country. Most people in the rich countries won’t see this though, just like people in a state far from the ocean won’t see the effects of emissions on coral reefs.

3. Arid Regions

Kyle Wyatt

Introduction: Ethics and Sustainability of Arid Regions

Prior to industrialization major population centers had to be based around areas that were resource rich enough to sustain them. Mega cities sprouted around fertile river deltas, the shores of lakes, and around bays. The ecosystem services provided by these locations served as a major form of capital that probably seemed endless when first settled. The Industrial Revolution changed all that; cheap energy, mechanization, and new transport methods allowed us to change the surface of the earth like never before and move resources around with ease. Regions with extreme climates and little to no ecosystem services were able to be settled and expanded at a higher rate than their existing resources would have ever allowed. Cities in the arid, US-Southwest only exist thanks to the cheap energy to provide them with air-conditioning and the huge aqueducts, dams, and diversions along the Colorado River watershed to bring them water and irrigate the desert. Moving into the 21st century, these areas are predicted to get hotter and drier with climate change. Less winter precipitation throughout the country will mean less summer snowmelt to keep an increasingly lower Colorado River flowing. Finally, as energy from fossil fuels becomes more expensive, it will be more costly to maintain the luxuries these cities have had in the past (Day 2014). Three American cities immediately come to mind in this region: Los Angeles, Phoenix, and Las Vegas. All three have expanded to the point of near-unsustainability and their ability to continue to draw on resources derived from other areas is not only a resource management question, but an ethical one as well. The history of these cities and the issues they face today will be explored, along with an example from Australia to explore whether the issues we face are uniquely American or global.

3a. Los Angeles

When the area that is Los Angeles was first surveyed by the Spanish in 1768, they found a flourishing wetland area, fed by the bountiful Los Angeles River. Over 20 Native American tribes lived in this area without the need of crops or agriculture, as food was so plentiful. Waterfowl and small mammals abounded, steel head trout spawned in the river and grizzly bear roamed its shores. The Spanish established a permanent colonial settlement in 1781, named El Pueblo de Nuestra Señora de los Angeles di Porciúncula, or Our Lady of the Angels, in honor of the Virgin Mary (Steen 2007). From this time until the mid-1800's the area's population primarily consisted of inhabitants of the San Gabriel and San Fernando Missions and 11 Mexican families who farmed the area. The 1840s brought rapid-fire change to the area. The US Military seized the city in 1847, Mexico ceded the entire state of California to the US in 1848, and, in response from demand triggered by the gold rush, LA was flooded with migration and increased demand for its cattle in 1849 (Discover... 2019). Although LA would only have 5,000 inhabitants in 1870, this number would jump to over 100,000 by the turn of the century, and only keep growing from there (Tzeng 2011).

Population growth of this kind traditionally has some growing pains. For LA, this meant discovering where settlers could and couldn't build if they expected to weather the area's devastating flooding. The Los Angeles River, whose source is the San Fernando Valley, flowed almost year-round and provided water to numerous other lakes, rivers, wetlands, and wells. The river was estimated to have been capable of supporting a town of upwards of 250,000 people if managed properly (Gumprecht 1999). Unfortunately, settlers were discouraged by the region's unpredictable weather; some years brought drought while others brought devastating floods. In 1938 following massive flooding in Los Angeles and Orange Counties, the US Army Corps of Engineers paved the River and its tributaries with concrete, sending floodwaters to the ocean as quickly as possible (Mcphee 1989). The decision to dump the primary source of freshwater into the ocean might well seem like the end of a city. However, LA had a different source of freshwater for quite some time by 1938. In 1913 the mayor of LA, Fred Eaton, faced the realization that the city could run out of water if its population continued to grow. The LA River flowed too unpredictably to be relied on alone. With help from William Mullholand, the LA water department and the US Reclamation Service quietly convinced farmers in the nearby Owens Valley to sell them over 200,000 acres of their water rights. In 1913 with rights to the water secured, they were able to construct a massive aqueduct over the mountains, directly to the city. With a diversion of this size placed on the watershed, the Owens Valley quickly transformed into a dustbowl of agricultural and economic ruin (Reisner 1993).

Today the LA area is home to over 4 million and is classified as the largest desert conurbation in the world (Debuys 2011). Los Angeles' current water usage plateaued around 700,000 acre-feet per year in 1986, despite growing populations and predictions that water usage would grow to over a million acre-feet annually by 2010 (Villaraigosa 2008, Sheikh 1991).

While this demonstrates the city’s ability to adapt to be more sustainable, the principle issue remains that the city still gets most of its water from distant sources. Water for urban use in LA comes from 3 sources: 36% still comes from the Owens River, although this number shrinks each year as increased aridity in the region means LA gets less to sustain the region; 52% is imported from both Eastern Sierra watersheds in Northern California and the Colorado River; and 11% from groundwater (USCViterbi 2016). The city has grappled with many strategies to increase water obtained from local sources; a 1991 report explored the possibility of the city reusing 80% of its wastewater by 2090 (Sheikh 1991). Recently the mayor of LA, Eric Garcetti, has expressed plans to recycle 100% of wastewater by 2035. This added water source could fill 35% of the city’s water demand. Another 50% would be sourced locally as well. Interestingly enough, there seems to be no plans to attempt to exploit the mass amounts of freshwater that flows from the LA River straight into the ocean every day. The LA River Index was created by stakeholders who wanted to explore the possible benefits of the river on the city. Over 25 years of historical flow data showed the LA River has an annual discharge of around 278,000 acre-feet, or around 40% of current water demand in LA. With such a source so close, it seems like LA is letting a major resource just flow by.

Climate change is no longer an abstract possibility of the future, but a clear challenge we are set to face Moving into the future, communities will have to become more sustainable. While many will rise to the occasion and work to flourish once again, we must explore the possibility that some are either beyond saving or too costly to do so. Climate change is going to affect the US Southwest the most compared to nearly any other area. Hadley Cells are areas of atmospheric circulation, they are formed by hot air rising on one end and the corresponding fall of cool air on the opposite. The climate change related expansion of these cells is set to increase aridity in this region, leading to more severe and sustained drought (Debuys 2011). Additionally, discharge out of the Colorado River Watershed is predicted to decrease anywhere from 5-20% by 2050, with Lake Mead and other major reservoirs to never fill to capacity again (Day 2014). It is for these reasons the southwest, LA included, are seen as one of the biggest threats to continued stability as we enter the 21st century. Even with LA’s planned water strategies, they will still require outside water sources that are constantly shrinking, all the while their own new sources may likely be not as ample as they hope. As areas scramble to remain sustainable, will we be able to justify continuing to send these resources to areas where they will be consumed without any benefit returned.

Los Angeles is working hard to remedy mistakes of its past. In addition to the Mayor's plans to reuse wastewater, there are plans to restore 11 miles of the LA River, bringing back its ecological habitat and function (City of... 2016). However, are these plans enough, or will they be just wasted effort if the Colorado dries up and Northern California shuts off the spigot to provide water to Central Valley agriculture instead? Obviously, LA is not going to roll over and die any time soon: as such they should make every effort to increase sustainability. While 11 miles of LA River is a good start, they should really begin planning to restore function to all 51 miles of the river. This will maximize the benefits in both freshwater that can be used for drinking and ground recharge. Lastly desalination should be explored, while a costly alternative now, as traditional water sources become scarcer, its cost will only decrease. By implementing changes like these Los Angeles can not only be seen as a draw on precious resources, but possibly a vision for future sustainability.

3b. Phoenix

James Shafer

Phoenix, Arizona is one of the fastest growing cities in the United states. What started as a small town in the south west has quickly become one of the largest metropolitan areas in the united states. Phoenix currently has a population of 1.626 million in the city proper. Since the year 2000 Phoenix has never seen a negative population growth. Phoenix first rose to prominence once military bases were established there during the early 1800s. Copper mining brought commerce to the area, and with it an increase in population. The Copper boom was small at first, but after several public projects and water became more available, Phoenix saw its first major population boom. In the late 1800's large scale irrigation projects bringing in water from the surrounding rivers, allowing for expansive population growth. During this time, Phoenix relied on production of cotton, cattle, and citrus. It wasn't until the 1950s and the mass production of air conditioning and an influx of high-tech companies that phoenix saw its "final" population boom (Odd 2015). Throughout the history of Phoenix there has always been a common trend, water. All this growth has been accompanied by a growth in infrastructure to secure water.

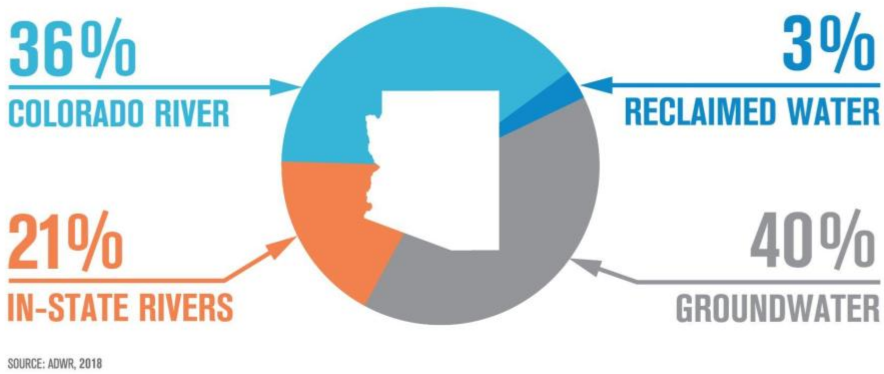


Figure 3.1: Arizona water sources.

The largest source of water for Phoenix currently comes from groundwater. Tapping into these slow recharge water sources requires extensive regulations. In Arid areas, these aquifers recharge very slowly and use can quickly overtake recharge this is referred to as “overdraft”. To regulate these aquifers and prevent overdraft, Arizona passed the Ground Water Management Act (GWMA). The GWMA is intended “to control severe overdraft occurring in many parts of the state, provide a means to allocate the state’s limited groundwater resources to most effectively meet the changing needs of the state, and augment Arizona’s groundwater through water supply development” (Protecting & Enhancing... 2019). The GWMA has designated Phoenix an Active Management Area (AMA). Requiring the city to have a net zero impact on aquifers.

The newest source of water to residents of Phoenix is reclaimed water. Although this source only accounts for 3% of Phoenix water needs, reclaimed water has quickly become popular, this proactive approach is key to the city's plan to manage water in the future. 95% of wastewater generated in the city is repurposed (Regulation, Use... 2015) Reclaimed water is cleaned and treated wastewater which is repurposed for agricultural, commercial and landscaping applications (Regulation, Use... 2015). “Recapturing” this water reduces the demand on potable sources for non-essential uses. Reclaimed water has been received well in this region and is viewed as a win-win for all involved, providing cheaper water, and reducing the demand on potable water.

Phoenix’s second largest source of water is from the Colorado River, this river encompasses seven U.S. states and two Mexican states. It flows from its headwaters in the central Rocky Mountains to the gulf of California in Mexico. Despite the scale of the Colorado, it is a very regulated source of water. Seven states in the United States rely on drawing water from the Colorado to help meet their needs. With this many states depending on one river, several laws have been drafted to ensure equal and fair use of this resource.

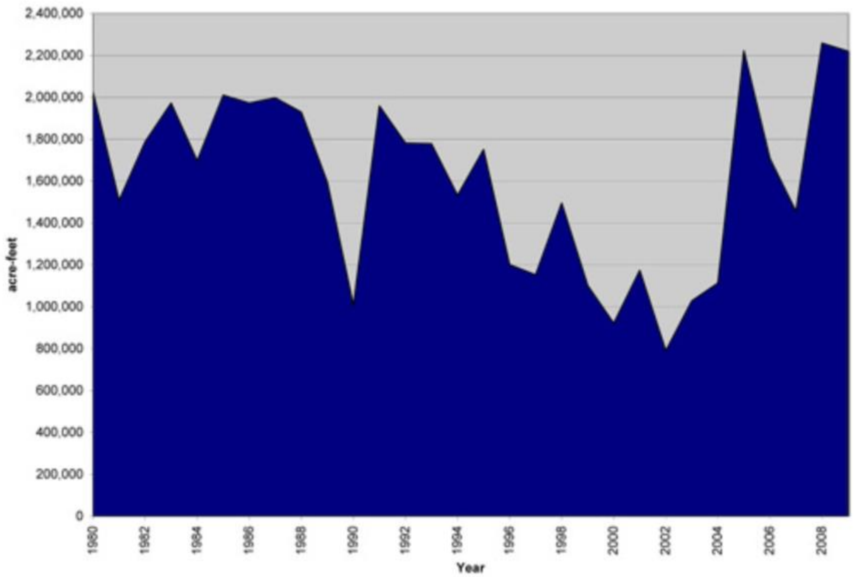


Figure 3.2: Annual water use by Arizona in acre-feet/year.

Phoenix also sources water from its in-state surface water, this makes up 21% of its total water use. Surface water in this context refers to mostly human made reservoirs and dams (Surface Water… 2019). The management of these reservoirs falls under the Salt River Valley Water Users Association, or the SPR for short. The control and release of these sources are all determined by the demand. The draw from the reservoirs is normally constant other than in drought years where reservoirs are drained more aggressively to help prevent overdraft in ground water. This can be seen in the graph where in 1989 and mid-1990 to 2002 a drought occurred, resulting in a decrease in reservoir depth as they were used to prevent overdraft. This diversification of water resources allows the area to be more resistant to extreme weather.

Faced with an intimate relationship with water resources, Arizona formed a state level department The Arizona Department of Water Resources (ADWR). Established in 1948 the ADWR first primary task was to pursue a Supreme Court Case against California, over access to

Colorado River Water (Arizona v. California … 2019). The case of Arizona v. California, 373 U.S. 546 set the tone for Arizona's water ideals. This is one of the first cases in which states took a proactive approach to managing water. Arizona v. California boiled down to one simple question, how much water was each state legally allowed to use out of the Colorado River and its tributaries. The ruling resulted in a division of the first 7,500,000 acre-feet of mainstream waters, 4,400,000 of which would go to California, 300,000 to Nevada and 2,800,000 to Arizona and finally that any surplus would be divided equally between Arizona and California (Justia Law, 2019). After a successful suit, the ADWR remained intact with a new goal. Today the ADWR serves a dual purpose. First it enforces and carries out Arizona water law, and decisions made by the government, second it serves as an educational source for Arizona residents, helping them better understand water law and water sources in the state and finally to provide data and interpretation of current water issues.

Water demand for arid regions, is a complex issue that should not be addressed on a small regional scale. Due to the size of watersheds and a multitude of users, these issues are best addressed regional. Several important lessons can be learned by looking at the greater phoenix area's relationship with water. First is that proactive measures need to be taken to prevent water issues. As droughts and extreme weather becomes more frequent, proactive water management can help reduce the strain on cities and their surrounding ecosystems. Second, that as a city grows water resources should come from an increasingly diverse set of sources. Diversifying water sources allows for more water security and flexibility as traditionally reliable inputs become more variable. Third, Water issues occur at a large scale and as such require multiple agencies to help manage them. Creating specialized agencies for each source of water allows for more tailored management practices to be implemented. Creating large population centers in arid regions may seem like an unethical practice, but by looking at Phoenix and its relationship with water it is clear that with proactive management, diverse water sources, and proper enforcement these areas can be settled with few issues. By examining Phoenix's water management, cities that are experiencing a change in water availability due to climate change may be able to adapt tried and true practices to better manage an increasingly rare resource.

3c. Las Vegas

Nathaniel Barnes

American settlers of the 'wild' west quickly realized that water availability was scarce when compared to eastern states. Due to this difference, the federal government was forced to come up with a new set of laws to manage the water rights. Their solution was the Prior-Appropriation Doctrine of the western United States, which was established in the mid-1850s at the federal level, following the California Supreme Court case *Irwin v. Phillips* (Benson 2011). The basis of the law ensured the water right to the first person to put the resource to beneficial use. So, once an individual was utilizing any water source for agriculture, industrial, or household purposes, no other person could legally reduce their water availability. Following the enactment of the Prior-Appropriation Doctrine, states began to develop their own water statutes to meet the individual needs of each area; though, the federal law is still the basis of all western water rights today.

The first water statute in the state of Nevada was enacted in 1866 which gave citizens the right to divert streams via ditches or flumes as well as provided the right of way through the lands of others (Welden 2003). The next major development in water law occurred in 1903 when the state created the Office of State Engineers whose sole responsibility was to define the existing water rights across the entire state (Pisani 1977). Just ten years later, jurisdiction to oversee all water rights was transferred to the newly created Nevada Division of Water Resources (NDWR) (Pisani 1977). The NDWR became the central entity in charge of all water use throughout the state and quickly began to address uncertainty surrounding rights to groundwater. The state of Nevada passed the Underground Water Act in 1939 which then granted NDWR jurisdiction over all groundwater in the state (Morris et al. 1997). This act would be amended several times in the following years but stood as a foundation for local government to establish their own regulations as well as a model for other western states to limit groundwater depletion.

The City of Las Vegas was founded in 1905 as a hub for the Union Pacific Railroad company (Land and Land 2004). At that time, the small town relied heavily on personal wells as well as the underground Las Vegas Spring to meet irrigation and industry demands. The State of Nevada entered into the Colorado River Compact in 1922 which would require upland states; namely, New Mexico, Wyoming, Colorado, and Utah, to not deplete the flow of the mighty

Colorado River below 7.5 million acre feet during any ten-consecutive-year period so that downstream states—Nevada, Arizona, and California—wouldn't be left out to dry (Mulroy 2007).

The Compact would become critical for the city of Las Vegas due to their close proximity to the river and their exponential population growth during the 1920s and 30s. However, the flow of the Colorado River was significantly changed with the building of the Hoover Dam in 1931 (Lavın and Sánchez 1999). President Herbert Hoover ordered the building of the dam to provide hydroelectric power for Arizona, Nevada, and California, as well as to create thousands of jobs for Americans during the Great Depression (Dunar and McBride 2001). The construction of the dam—just 31 miles outside the city center—led many Americans and their families to settle in Las Vegas, shifting the town from a quaint railroad hub to a growing metropolis situated in the desert.

Because the groundwater supply of the Las Vegas Valley could not keep up with the growing demands of the city, state officials passed a bill which would allow county voters to create a local water district to better meet specific needs (Jones and Cahlan 1975). Soon after, the Las Vegas Valley Water District (LVVWD) was created with a seven-member board of directors elected by the citizens of Las Vegas (Pavelko et al. 1999). The first goal of the LVVWD was to apply the state's Colorado allocation rights to begin reverting surface water from Lake Mead to partially relieve the high demands placed on wells and springs. Next, the LVVWD was then able to purchase all water rights previously owned by the Union Pacific Railroad in the Las Vegas Valley for $2.5 million (Mulroy 1993). This led the city government to drill more wells throughout the valley in the 1950s as it was a cheaper water source for citizens of Las Vegas when compared to transporting water from Lake Mead.

The population of Las Vegas continued to grow in the 1960s and 70s, as military personnel were stationed at the Nevada Test Site following World War II as well as during the Cold War. The groundwater supply for the valley was dwindling, and local geologists began to observe land subsidence and fissuring throughout Las Vegas Valley (Bell 1997). The LVVWD quickly developed construction plans for the Southern Nevada Water System (SNWS), which would transport and treat more water from Lake Mead (Stave 2003). The water delivery system took over 14 years to complete, but once it became operational, it could provide 400 million gallons of treated Colorado River water for Las Vegas Valley District (Rogers and Moonin 2014).

The city of Las Vegas continued to grow and quickly became a top tourist destination in the American Southwest in the 1990s and early 2000s. Population growth along with a greater influx of tourists heightened the demands on the valley's water supply. The overall water demand for Las Vegas Valley surpassed 400 million gallons per day in 1999, which was surpassed only seventeen years after the completion of the SNWS (Salvaggio et al. 2014).

Since 2007, the city of Las Vegas has experienced a 5.5% annual growth rate and is among the fastest growing metropolitan areas in the nation (Deacon et al. 2007). The Las Vegas Valley Water District has adopted strict water use policies and modern technology to reclaim water since they are now serving over 3 million people in one of the driest places in the United States. Although highly praised and seemingly successful, the LVVWD is currently facing two major challenges: groundwater depletion and insufficient ways to reuse drinking water.

Foremost, the entire Colorado River watershed has experienced a drought over the past nine years which has limited the surface water recharge of Lake Mead (Castle et al. 2014). Beneath the surface, groundwater storage throughout the watershed is being depleted at a rate of 5.6 km^3 per year (Castle et al. 2014). In the Las Vegas Valley, overusing groundwater has led to land subsidence and entire aquifer system deformation (Amelung et al. 1999). Areas of Las Vegas have subsided by over two meters due to groundwater depletion (Amelung et al. 1999, Bell et al. 2002). In spite of this knowledge, the LVVWD still relies on various groundwater sources for over ten percent of their total water budget.

Second, water quality in the Colorado River has decreased drastically over the past decade. All wastewater effluents and runoff generated within the Las Vegas Valley are processed and transported back to the Colorado River via the Las Vegas Wash system of the SNWS. However, the water being dumped back into the river has escalated levels of total dissolved solids due to interactions with salt compounds in metropolitan areas (Venkatesan et al. 2011). The increased salinity levels in the Colorado River are estimated to cost downstream agriculturalists $306 million per year. If LVVWD cannot improve the wastewater quality to standards similar to pre-use levels, Las Vegas may lose their right to transport water from Lake Mead which accounts for almost ninety percent of their total water budget (Roefer et al. 2000).

Models developed by the SNWS have predicted that water demand will surpass supply for Las Vegas Valley by 2025 (Stave 2003). The options are to increase supply or reduce demand. As previously mentioned, the LVVWD's current water sources, groundwater and Lake Mead, are exhibiting signs of overuse and neglect that are unsustainable. Additionally, transporting water from sources outside the valley is too expensive and a logistical nightmare. So, the LVVWD has turned to reducing demand through implementing strict water use policies and incentivizing minimal water use practices. Installing turf yards, using mist irrigation systems, washing your vehicle at home, and the use of outdoor fountains or other ornamental water features have all been banned from home and businesses in Las Vegas Valley (Joyce 2004).

The LVVWD has also recently introduced price rationing to encourage residents to use less water for monetary savings. These efforts have helped decrease water consumption in Las Vegas Valley by 32 billion gallons between 2002 and 2014, even though the area experienced an influx of 520,000 people over the same time period (EPA 2016). Even though these results are promising, the water sources for Las Vegas Valley are finite. The LVVWD is currently working on advanced reclamation systems to repurpose sewage waste back to drinking water standards so they could be completely reused not just for lawn irrigation (Hinton 2014).

Water scarcity in Las Vegas has been an issue since the area was first settled in the early 1900s. The booming city has relied too heavily on surface water from Lake Mead and groundwater wells throughout the valley and has consequently degraded both sources to unsustainable conditions. In lieu of this knowledge, Las Vegas continues to experience population growth and urban expansion, which only magnifies the stress on water availability. Local and state governments will soon be forced to make tough decisions to further regulate water consumption before the entire valley dries up. Policy makers must answer questions, such as how to ethically allocate water rights to 3.1 million individuals currently living in Las Vegas Valley, before this crisis gets out of hand.

3d. Australia

Morgan Katsch

Brisbane is the capital city of Queensland, Australia and is one of the fastest growing cities in the world. It is rated as one of the most livable cities in the world (World Population review 2019) with a population of 2.27 million, growing at 2.7% per year. The climate within Australia is very erratic, often fluctuating from one extreme directly to the other. Years of droughts that are broken by catastrophic floods, the various climates within Australia are largely influenced by El Nino and La Nina which both warms (El Nino) and cools (La Nino) the climate within Australia. The climate is governed mostly due to its size and by the sinking, hot air of the subtropical high-pressure belt, which moves both south and north with the seasons. The three major climates within Australia include; tropical in the northern parts, temperate in the southern parts and desert/ arid within the central regions. Australia is the second driest continent in the world with almost 70% of the land deemed as arid. This arid climate has been present since humans first settled the continent in 1788 with an overall increase in temperature by around 1°C since 1910 (Head et al. 2015).

Water storage, treatment and supply for Brisbane is managed and handled by South East Queensland Water (SEQ Water). The three major water sources which supply Brisbane include: Wivenhoe Dam on the Brisbane River, Somerset on the Stanley River and North Pine on the North Pine River. There are also various other smaller dams connected within the SEQ water grid, which provide Brisbane with water supply. SEQ Water manages around $11 bn of water supply infrastructure such as the SEQ water grid, this infrastructure ensures a reliable and safe drinking water supply for more than three million consumers across South East Queensland.

There are several issues the residents of Brisbane are facing with regards to water supply and demand. The average resident is consuming and using more the 30L extra of water per day compared to 12 months ago (Moore 2018). Figure 3.3 clearly highlights the increase in water consumption and highlights the need to introduce water saving techniques to deal with this increase in the arid climate of Australia.

A severe drought between the years of 2009-2011 prompted major investments into how the water supply of Brisbane is managed. A $2.5 bn water project called ‘Western corridor recycled water project’ was constructed which include three wastewater treatment plants, over 200km of pipelines and 13 pumping stations. This project was triggered from the drought and was designed to provide reclaimed water to all industries such as agriculture and industrial as well as supplementing drinking water supplies received from the Wivenhoe Dam.

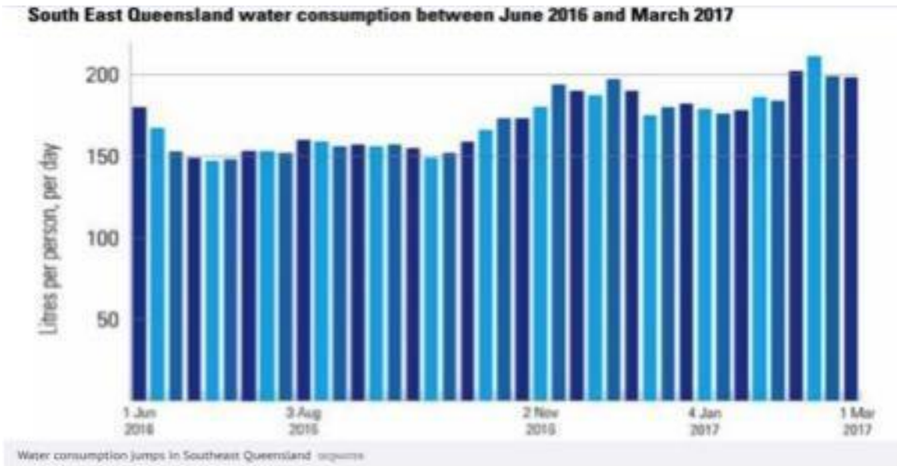


Figure 3.3: SEQ water consumption between June 2016 – March 2017. (Moore 2018).

Another issue Brisbane faces with regards to water supply is the effect of urbanization on groundwater. Due to Brisbane population being one of the quickest growing in Australia the demand for water increases putting greater pressures on the supply to hand the continuous population growth. Ground water is a vital resource within Australia as it provides a natural water source for agricultural, local ecosystems and drinking supply for residents. Between the years of 1983 – 1996 Australia's reliance on groundwater increase by 90% (Moore 2018). Thus, the increase in development of building infrastructure results in the decrease in available ground water. These impacts on ground water are a result from various different negative practices which include: changes in land use from agricultural to residential; rising water tables as a result of termination of extraction for irrigation; declining water tables in areas where irrigation has increased; decreasing quality of ground water, due to the introducing of nutrients such as fertilizers; occurrence of acid saline waters in coastal sediments as a result of industrial activities (Cox et al. 2016). Therefore, water smart development practices need to be constructed when building new houses and the reduction of urban sprawl techniques such as better public transport need to be utilized to decrease the impact on this vital resource.

Salt-water intrusion is the movement of saline water into freshwater aquifers or ground water and leads to the contamination of natural drinking water. Salt-water intrusion occurs naturally along coastal areas such as Brisbane due to the saline ocean water mixing with the fresh water, although due to excessive irrigation and urbanization salt-water intrusion is happening further inland in areas where Brisbane's water supply is sourced and thus brining about issues with their drinking water. Figure 3.4 illustrates how salt-water intrusion occurs. A study of the

Pioneer Valley which is located 50km inland of Brisbane in the same location as one of their three major water supply sources has highlighted how excessive irrigation for sugar cane (Werner 2016) has led to the saltwater intrusion of the North Pine river. The study constructed a model that successfully reproduced observed salt-water intrusion into the groundwater as a result of excessive irrigation on agriculture land. The excessive use of irrigation both raises the water table and then allows the saline water to mix with the ground water, thus contaminating it, but also runoff of fertilizers into the rivers and streams causes a reaction from which turns the water saline and unsuitable for drinking (Werner 2016). Techniques that are currently being used to manage and remove the issue of salt-water intrusion into Brisbane's water supply include drip irrigation. This form of irrigation has many benefits that include runoff of fertilizers is removed, decreased water usage and more efficient crop growth has plant roots are targeted directly (Raine 2015).

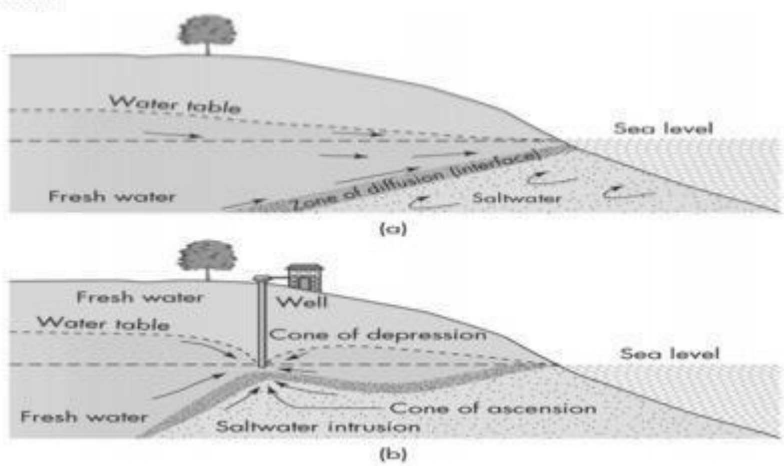


Figure 3.4: Saltwater intrusion process. (Shott 2016).

Another technique utilized by the Brisbane City Council to reduce salt-water intrusion into ground water is the reduction of urbanization. As stated earlier, when urban sprawl occurs large areas of forestry are often removed which impacts the ground water as these trees keep the water table below the ground water and when removed it provides the opportunity for the water table and ground water to mix, thus ground water is now contaminated and unhealthy for consumption. The Brisbane council has provided the residents with increased public transport options and has re zoned land within the city as 'open space', which prevents the construction of housing developments on large areas of green space (Brisbane City… 2019). These methods both reduce the need for urban sprawl, and maintain a healthy level of the water table, while reducing the possibility of the contamination of ground water.

As a result of climate change and Australia's already arid climate there has to be water resource management practices put into place to manage the supply of water to meet demands, control saltwater intrusion and better educate residents with regards to smart water practices. These water management practices should be addressed on a large regional scale. The Brisbane city council works with residents and industries to better manage and control the consumption of this vital resource through rules and regulations. Key practices are outlines below which are placed at a regional scale to address potential desalination processes.

Brisbane city council states the need to reduce demand from coastal ground water resources. Over the last decade Australia has more than doubled its intake from ground water (Henderson 2016). Ground water as a source now makes up around one fifth of water consumed within Australia and that is further increased in the city of Brisbane that consumes almost a quarter (Davis 2016). A study from the 'Natural edge project' highlighted that although the consumption of ground water makes up a quarter of all supply, the interaction between ground water and saltwater intrusion is still widely misunderstood and thus unable to effectively manage ground water in a sustainable way. As the excessive extraction of ground water is the main cause of salt-water intrusion alternatives such as bore water must be considered.

Another key action Brisbane city council is aiming to implant is the introduction of coastal barriers. In areas where the salinization is due to storm surge, coastal barriers would significantly reduce or prevent these surges from reaching the land and soaking into the ground water. As a result of climate change increased large storms are hitting the Australian coast and thus producing more frequent storm surges (Bureau of Meteorology 2019) and the added risk of rising sea levels places even more pressure on the potential of saltwater intrusion occurring. An example of where this process has been used is in the Netherlands, where $1.5bn was spent to construct a large sea wall to prevent storm surges from reaching the city.

Therefore, these strategies assist Brisbane in evaluating and maintaining the ethical issues surrounding the vital resource of ground water as a key water supply for the city. These strategies also prevent salt-water intrusion, and the contamination of the natural water resource. Further strategies such as regulations on ground water extraction can be used under extreme circumstances.

Conclusion

Climate change is a reality the entire world must face. Cognitive dissonance is not an appropriate course of action moving forward. While the sustainability issues facing arid regions are not unique to the United States, it is our responsibility to lead the charge in preparing these cities for the problems they face today and the future. By better realizing the ecosystem services that are present in these regions, having resource conservation as a primary goal, and pursuing more environmentally friendly technologies, we can not only survive the changing future we face but flourish in it.

Chapter 4: Fire

4a. Fire Ecology in the Western United States

Elizabeth Rieger

Fire is a natural component of ecosystems in much of the Western United States. This has caused many plants to evolve in different ways to coexist with the pressure of fire. Long-lived species have evolved many strategies to live with fire including avoiding, tolerating, and embracing fire. Plants classified as fire-avoiders and fire-refugees are not well adapted to fire. They are generally found in areas such as riparian zones and alpine environments where fire is rarely present, and thus do not have a need to change their life patterns to accommodate fire. Fire-tolerators and fire-embracers, on the other hand, have evolved to live with the presence of wildfires. Mature, fire-tolerating trees can survive multiple fires of low-intensity due to features such as thick bark and the self-pruning of dead branches. Thick bark protects the important inner parts of the tree from experiencing heat shock when exposed to fire and self-pruning removes lower branches that would allow fire to spread to the crown of the tree. An example of a fire-tolerator is the ponderosa pine which spans a large portion of the Western US. Fire-embracers, conversely, don't always survive fire, generally have thinner bark, and do not self-prune. However, they often require fire for reproduction. Fire acts to open up cones and provide an adequate site for seedling recruitment. An example of a fire-embracer is the lodgepole pine which is dominant in many forest types (Keeley 2012).

Fire also has direct effects on the plant community. It may have a positive effect on plants by provoking them to release their seeds or begin flowering. Similarly, when some plants are burned, they begin to vegetatively reproduce and produce more biomass than before the fire. Fire may also create a habitat with less competition that allows certain plants to grow without being restricted by light, moisture, or nutrients. Alternatively, fire can also have negative effects on some plant species. It can destroy seedbeds in the soil, making them no longer viable for germination, and severely restrict growth of plants that are not fire adapted (Wright and Heinselman 2014).

Besides influencing plants, fire also has many short and long-term effects on other components of the biotic and abiotic environment. Food sources for herbivores can either increase or decrease when burned and may change as the environment undergoes succession after the fire. In turn, the impact on carnivores will depend on the effect the fire had on the species they prey on. Fire will also affect the habitat in which species live, either making it more or less habitable. This is true of forest insects who require trees/ vegetation as a host. If there is no host, populations will decrease (Wright and Heinselman 2014).

In regard to the abiotic community, fire results, directly or indirectly, in the release of mineral elements through the burning of organic material and increased decomposition rates. Soils can also be influenced by a reduction in the litter layer and the material shading the ground, thus increasing insulation and changing the soil temperature and moisture. Fires also alter the net amount of carbon in an ecosystem. There can be an input of carbon and organic material due to increased carbon recycling, dead organic matter, and primary production. Conversely, there can be a decrease in carbon and organic matter if it is consumed in the fire (Wright and Heinselman 2014).

Site specifics and the combination of plant species making up an ecosystem determine how intensely and often an area will burn and how recovery will progress post-fire. The U.S. Forest Service has outlined eleven fire groups in Western Montana alone that consist of different habitat forest types. These fire groups all have different dominant tree and understory species that affect the amount and type of fuels, the role of fire in the area, and how succession of the forest will progress after fire. This is important to understand as not all forest types will respond to fire the same way and may require special management considerations (Fischer and Bradley 1987). Similarly, fires in different ecosystems will have different return intervals. Some areas may naturally experience frequent fires with a fire return interval as low as 10 years. Other areas rarely burn and may have a return interval with more than 500 years in between fire events (Agee 1998).

Due to the varying outcomes of fire in different forest types, the consequences of a wildfire be generalized across a landscape. Historically, most forests were heterogeneous and contained different tree species as well as varied densities and compositions throughout. Thus, one fire regime cannot be assigned to fit all forests in an area. Depending on the vegetation, climate, and amount of fuel, an area may experience low, moderate, or high severity fires, or a mix of these (Williams and Baker 2012).

For example, in the Colorado Front Range, fires have historically been of a mixed severity, with most being moderate to high severity. Low severity fires generally burned at lower elevations on gentle slopes. These fires were often on sites composed of stands of pure ponderosa pine, which are tolerant of fire, but also occasionally burned in mixed conifer stands. Mixed severity fires, on the other hand, burned in all of the dominant forest types of the area including pure lodgepole and ponderosa pine stands as well as mixed conifer stands dominated by either aspen, lodgepole pine, Douglas fir, or ponderosa pine. Areas that supported mixed regime fires spanned a broad range of topographic features, often at elevations above 2236 meters and on slopes of four degrees or more (Sherriff et al. 2014).

The Klamath Mountains in Southern Oregon and Northern California have a dissimilar climate and support different vegetation communities than in Colorado but still experienced mixed severity fires in the past. However, in this region the dominant fire type was low severity, with few high severity fires and some of moderate severity (Odion et al. 2014). Taylor et al. found that the severity and return interval of fires in this area was most affected by temperature (a result of elevation) and soil moisture as these variables strongly influence species abundance. The warmer, low elevation sites supported mostly pine species, leading to a greater accumulation of fuels than on higher elevation sites that supported fir species. As the lower elevation sites also supported more growth after a fire, they also burned sooner after previous fires than higher elevation sites. The slope of an area also greatly influenced the severity of the fire. Mid and upper slopes were more likely to experience high severity fires as the canopy cover of trees on steeper slopes reach closer to the ground and fuels are preheated when fires move uphill, making these areas easier to burn and more likely to spread crown fires (Taylor and Skinner 2003).

Understanding how forests have burned in the past will prove to be extremely important in analyzing how wildfires are changing. Due to a combination of past management and climate change, the fires burning today are often much larger and intense than in the past. Beginning in the early 1900s, land managers pushed for fire suppression in the hopes of protecting valuable timber resources. However, over time, this has resulted in an increase of burnable fuels in the forest. Similarly, with a suppression of fires, forests have become less diverse in structure types as well as the composition of species (Taylor and Skinner 2003). They have also become denser and less resilient to disturbance. This increases susceptibility to disease, insect infestations, and ultimately wildfire. As a result, fires in more recent decades are burning larger areas of land, are more expensive, and are much more damaging to ecosystems as well as human communities (Calkin et al. 2015). Human caused climate change is amplifying the effects of past management, as climate is becoming more favorable for wildfire. Factors driving this include increased temperatures, fuel aridity, water deficits, and length of the fire season (Abatzoglou and Williams 2016). Ultimately, fires are exceeding natural and historical intensities and sizes due to the actions of humans.

4b. History of US Fire Management in the West

Erik Killian

As humans move into ecosystems which naturally burn, we must develop ways of living with and around wildfire environments. Fire management first became an importance to the American people as settlers started moving west. The timber industry was worried about forests burning down their plots. In 1905 President Theodore Roosevelt created the US Forest Service. Their goal was to protect the timber and water quality of the United States. Over the years this goal has expanded to include managing wildlife, grasslands, and recreation. The Forest Service also looks after national forest land.

The need for wildfire management was proven in 1910 by what came to be known as the Big Blowup. During an exceptionally dry summer, lightning strikes started many fires in the west. Made worse by high winds, the fires spread to burn 3 million acres of forest in a matter of 2 days. In total, there were 86 casualties, and a mining town was destroyed (Egan). This event solidified the idea in fire managers and the American people that fires were dangerous and should be prevented at all costs.

The Big Blowup solidified the practice of fire suppression across the United States. Fires were to be put out as soon as possible, wherever they started. In more rural areas, watch towers were built to manage large swaths of unpopulated land. This practice seemed to work well, as there were no large fires for the following decades. The issue with fire suppression would take many more decades to become known. Fuel loads and tree density would slowly increase to dangerous levels.

During World War Two, lumber was a vital part of the American war effort. Wood was used to build all sorts of equipment including ships, gun stocks, and fortifications (Forest History Society). The government was worried that the Japanese would attempt to burn down forests to cut off American production. A compounding problem was that most would-be firefighters were drafted into the military. To combat this, the Forest Service began advertising campaigns aiming to employ all citizens to help in wildfire management.

The first of these advertisements starred Bambi from the popular Disney movie. To the public, these messages warned against wildfires as a way to protect animals. The wildlife was portrayed as in need of help by the American people against the dangers of wildfire. This propaganda against wildfires began turning the average American against wildfires, even those living far out of danger. During this time the science of ecology regarding forest fires was not well known, so policy was created without scientific input.

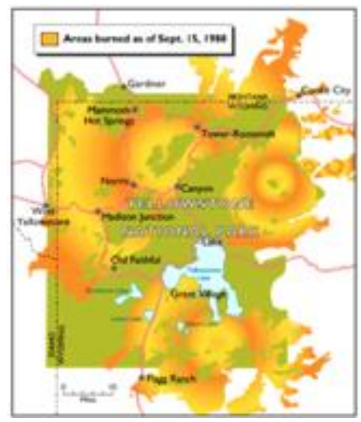
After the success of their first advertising campaign, the Forest Service created their own mascot against fires; Smokey Bear. Playing on the patriotic Uncle Sam posters used to recruit for the military, Smokey Bear stated that “Only You Can Prevent Forest Fires.” This campaign combined the public’s sympathy for wild animals and the sense of duty to their country, which at the end of World War II was extremely high. Again, this campaign was lacking in scientific input. At the time the benefits of wildfire were unknown, and not considered. Ecosystems which rely on fires for succession were becoming stressed.

After the war, the Forest Service and US government came to understand that the timber industry was a massive enterprise which needed to be protected. In order to make more educated decisions on how to manage forests and wildfires, the government created large funding opportunities for scientific studies across the western US. The consequent spike in scientific findings throughout the 1960’s and 1970’s came to common conclusions; wildfires are a natural process in some ecosystems, and the organisms within these ecosystems are adapted to coexist with fire (Marlon 2012).

These new findings accumulated in a large swing to wildfire management. The Forest Service decided to implement the Let It Burn policy. Natural wildfires were left to burn naturally, only to be fought when in the vicinity of human infrastructure. The public were highly skeptical of this new strategy, seeing it as much more dangerous than keeping the fires from burning in the first place. This anxiety was put to the test not long after, in the Yellowstone fire of 1988.

Yellowstone National Park is an example of the forests one would find in the western US. The largely deciduous trees rely on fire to remove old growth and establish germination of new seeds. Other than one other small fire in the 1930's, fires in the park were suppressed since its declaration as a park in 1872. Unnatural forest succession caused by wildfire suppression led to an accumulation of dead wood throughout the park. This led to an inevitable fire which would end up burning 1.2 million acres, over 600,000 of which was inside Yellowstone park (Marlon 2012).

The Yellowstone fires of 1988 brought fire management into the homes of Americans all over the nation for the first time. Headlines throughout the summer highlighted the "destruction of Yellowstone" and failure of fire management practices by government officials (Smith 2017). Many politicians were put under investigation for how they let this happen, with even president Ronald Reagan having to defend himself by pleading ignorant of the let it burn policy. The media failed to relate how wildfire was a natural process in this ecosystem, so many Americans saw this as an objectively negative event. This began the debate on fire management. Should wildfires be put out immediately or left to burn their natural course? This question is still debated among fire managers and the public, largely due to a difference in priority. Fire managers think on long term scales about health of forests, and how suppressing fires will lead to fewer, but more intense burning. The public enjoy living in and around forests which are likely to burn. Once a house is built, they would like to see everything done to keep their homes from burning.



Scientific understanding is a vital part of this debate. Before the 1960's, fire management was based on the timber industry. Trees were seen as a natural resource, so they were to be maintained at all costs. This led to unnatural accumulation of trees in forests designed to burn. Since learning about how these ecosystems function naturally, we have fought over how to manage the land because it does not coexist easily with our way of lives. Scientific understanding can help guide the debate, but it has no spokesperson or wealthy investors to move policy on its own. In the 1970's scientific knowledge helped change fire management policy to coincide more evenly with natural process. The scientific community, unbiased by nature, has a duty to communicate the facts, which policy makers are trusted to use in guiding policy.

4c. Ethics in Environmental Science: Fire and the Wildland Urban Interface

Lauren Saint Pierre

Wildfires play an integral part of various ecosystems locally and globally. Some forest functions rely on the presence of wildfire; like forest succession and overall forest health. Recently, the western United States has been experiencing some of the worst wildfire seasons of the past decade; in 2009 there were 75,018 reported wildfires with over 5.7 million acres burned and in 2015 there were 54,340 reported wildfires with over 9.75 million acres burned (National Interagency Fire Center). Historically, this is infinitesimal compared to the number of acres burned by wildfire before the Big Burn of 1910 and the implementation of fire suppression campaigns like Smokey the Bear. The question is: why have wildfires become such a pressing issue in the United States?

Humans have unremittingly altered fire regimes since the beginning of humanity, however in recent decades fire regimes have been marked with extreme changes because of an increasing population growth and demand for various socioeconomic amenities (Pausus and Keely 2009). It is imperative to understand the impacts of a growing human population on surrounding ecological systems.

It is projected that climate change will increase fire frequency in the future, and with little understanding or knowledge of wildfires and wildfire regimes, is it ethical to continue to expand into these areas? This paper will focus on the issues associated with the wildland-urban interface, human population growth, and wildfire potential of the contiguous western United States including; Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming (hereinafter "western United States").

The wildland-urban interface (WUI) is the area where house proximity to flammable wildland vegetation pose the greatest risk to people and their livelihood (Hammer et al. 2009). For an area to be considered WUI it must contain at least one housing unit per 40 acres (Collins 2005). The vast majority of wildfires are human caused and are ignited within the WUI (Radeloff et al. 2018). Wildfires that burn within the WUI frequently destroy houses and are arduous to fight. There are two main types of WUI: (1) the intermix and (2) the interface. The intermix is the area where houses and the wildland intermingle, and the interface is where the urban areas abut wildland vegetation (Figure 4.1). For an area to be considered intermix, more than half of the questioned area must be vegetated; for an area to be considered interface, less than half of the area is vegetated but is within 2 miles of a large area with more than 75% vegetation (Hammer et al. 2009). Of the total WUI area in the United States, about 80% is deemed intermix and the remaining 20% is deemed interface. However, WUI homes are split equally into the intermix and the interface (Hammer et al. 2009). In 2000, only about 3% of the total land area was WUI in the western United States, but roughly 11 million homes were located there (National Interagency Fire Center.

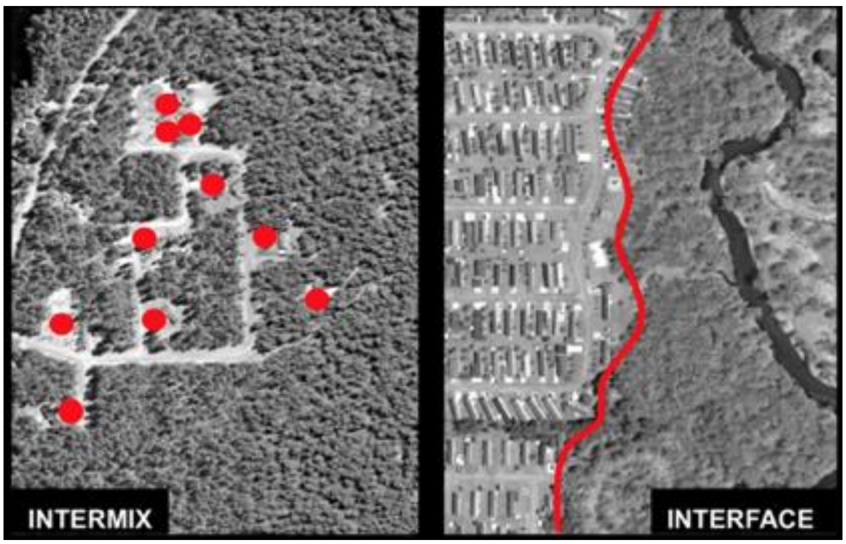


Figure 4.1 is the illustrated difference of the wildland-urban interface and intermix. The intermix (left side) and the interface (right) are different but often times conjoined.

Globally, human population growth is expected to reach 9 billion people by 2050. As of 2018, the United States population is 327.2 million people and is expected to reach 360 million by 2030. The western United States population in 2010 was 72.1 million and grew to 78 million people in eight years (United States Census). The majority of western United States is predicted to see growth greater than 15% (Figure 4.2) due to natural increases (births) and migration from midwestern and eastern states. The demand for housing is going to rise with the population.

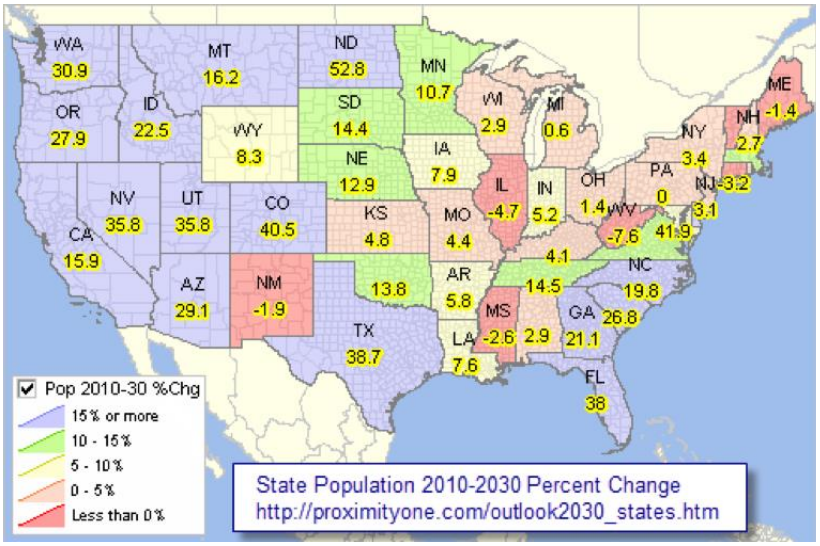


Figure 4.2 depicts the projected population growth by between 2010 and 2030 by state.

While there is ample evidence that WUI houses are problematic in terms of wildfire management and prevention, it is unclear as to how fast this area is growing. There are two events that can create new WUI areas: 1) new homes are built in an undeveloped wildland area; or 2) pre-existing developed or abandoned areas are revegetated. Both means are contributing to the current expansion. Understanding how and why the WUI is growing is crucial when creating and evaluating wildfire management policies, including fire adapted communities and fuel treatments. The WUI occupies less than one tenth of the land area in the contiguous United States, however 43% of all new homes were within the WUI and 59% of those were built in areas not previously designated WUI in 1990 (Radeloff et al. 2018). Assessing both the intermix and the interface, the intermix was more extensive and enlarged 1.9% from 1990 to 2010 compared to the interface that only enlarged 0.4% from 1990 to 2010 (Radeloff et al. 2018). Although the main cause is unclear, the demand for housing is potentially adding to the growth of WUI area (Radeloff et al. 2018). Population projections suggest that by 2030 the western US will have gained an additional 12.3 million WUI units. WUI expansion is also due to the decreasing average household size, interregional migration, and multiple home ownership (Hammer et at. 2009). Areas surrounding the WUI are attractive and lure residents into these areas. The social and economic factors of these areas impel growth as they are inexpensive and close to natural areas and recreation.

Many homes in the WUI are at risk of wildfire, but the potential for economic damage is greater in some areas than in others. Climate, ecological factors, and vegetation type are important in calculating wildfire potential (Alexandre et al. 2016); however, the pattern and density of WUI housing is often overlooked (Stein et al. 2013). Houses built within the WUI are subjected to two wildfire related issues: ignition potential and loss of livelihood. The more houses and people in a wildland area, the greater the ignition potential is. The National Interagency Fire Center recorded that 85% of wildfires from 2001 to 2011 were ignited by humans. Wildfires that burn close to homes are more difficult to fight and allowing natural fires to burn becomes nearly impossible (Radeloff et al. 2018). The more fires that burn near urban areas, the more likely homes and other structures will be destroyed, causing grief for homeowners and community members.

Although ecologically and demographically very different, California and Montana have been facing issues related to an expanding WUI. In Southern California, 3,079 structures were destroyed by WUI fires and suppression costs totaled close to $300 million in 2007 (Hammer et al. 2009). In Montana, 39% of the area granted wildfire protection is within the WUI and 66% of the fires suppressed in 2007 occurred here and the cost of suppressing a WUI fire was 46% higher with similar initial attack success rates (Hammer et al. 2009).

Homes that were built within previously burned areas can be used to assess how greatly WUI growth impacts wildfires and fire risk. There was a 26% growth in homes built from 1990 to 2010 in areas previously burned by wildfires (Radeloff et al. 2018). Homes that were built prior to wildfire are of concern because they pose a risk to firefighting, however, those built after fire are of even more concern because there is no indication of fire risk adaptations.

Humans have been continuously altering fire regimes with an increasing population growth and demand for housing with little knowledge of their actions. A growing population and continuous expansion of the WUI will impact a multitude of natural resources management related issues: like wildfire management, forest productivity, and ecological change (Hammer et al 2009). It is crucial to recognize the issues revolving around a growing human population, the increased demand for housing, and the impacts a growing WUI has on the surrounding environment. Wildfires can be extremely harmful and devastating, especially when environmental factors create extreme conditions and WUI communities are ill prepared. It is projected that climate change will increase fire frequency in the future and with little understanding or knowledge of wildfires and wildfire regimes people in these areas are at risk. To keep communities safe and to continue to coexist with wildfires, adapting and educating communities will be society's most effective tool.

4d. Changing Paradigms in Wildfire Management

Mac Murphy

The United States has viewed wildland fire management through a socio-economic lens since the first half of the 20th century. The scientific knowledge then regarding the role of fire in ecosystems was incomplete, and social pressures put a greater emphasis on development and resource exploitation than on conservation (Busenberg 2004). As a result, fire management focused on full suppression of fires across the landscape in order to protect private property and the economic value of natural resources. Removing fire from the landscape was a virtuous effort for the greater good of mankind. However, this scientifically ill-informed effort had unforeseen consequences that manifested by the turn of the 20th century. As the understanding of the ecological role of fire in natural systems increases new ideas are emerging for how wildland fires should be managed in the future.

Increasing fire return intervals through direct fire suppression has disturbed a major regulatory force that has maintained a mosaic of vegetation age and structure across the landscape. The legacy of fire suppression resulted in the loss of landscape diversity, biomass accumulation, and increased fuel bed continuity. These changes in ecosystem structure and function have been further accelerated by climate change, which has set the stage for more fires in western landscapes (Schoennagel et al. 2017). As human populations grow and expand into wildlands, communities increasingly come face to face with the realities of living in a fire-adapted landscape. Disastrous human interactions with wildland fire, media coverage, and governmental propaganda like Smokey Bear, influence a negative perception of fire by the public and policy makers (Ingalsbee 2015). Political pressures asserted on fire managers fuels a positive feedback cycle of costly fire suppression efforts that lead to increased fuel accumulation and inevitably results in increased occurrence of large fires (Ingalsbee 2017). Due to the apparent success of fire suppression operations in their infancy, fire managers are stuck suppressing fires despite growing consensus within the wildland fire community that this is not a sustainable management strategy.

A disconnect between scientific knowledge and public perception must be addressed for management to move forward. Our understanding of wildfire ecology has increased, and the role of fire regimes in creating and maintaining biodiversity is widely accepted (He et al. 2019). Many ecosystems have evolved with fires acting at different frequencies and intensities across a landscape. Fire suppression has changed the timing of fire disturbances which has led to increased fire intensities seen in recent years. The re-integration of fire into fire adapted landscapes is currently gaining more traction (Stephens et al. 2016), and the use of fire as a tool can restore ecological processes when applied at a landscape level.

Prescribed burning and wildland fire use are management tools used by fire managers to meet management objectives. Prescribed burns are planned ignitions conducted under desirable conditions with controls in place to contain the spread of the fire. A prescribed burn reduces fuel loads and creates heterogeneity in the landscape (Fernandes and Botelho 2003). The reduction of fuel can moderate the severity and influence timing of fire return intervals in the future. By burning patches of a landscape, managers seek to increase spatial variation of vegetation across the landscape. This promotes heterogeneity of age classes which drives biodiversity. In some cases, wildland fire use, or allowing a naturally caused fire to burn, can be used to meet management objectives. This most often occurs in rugged areas where human communities are not threatened and where firefighters would be exposed to unreasonable risk. Management objectives of wildland fire use are often the same as those of prescribed fires (van Wagtendonk 2007). However, these ignitions are not planned and a wildland fire can be a much longer duration event than a prescribed burn. Wildland fires can burn out in days or it can take months depending on conditions. These fires cause much larger inconveniences to people, such as prolonged exposure to smoke and public land closures. Wildfire use is most common in wilderness areas and wildlife refuges, but its use is expanding to other lands. Both prescribed fire and wildland fire use can provide resource benefits that can only be achieved with fire.

Unfortunately, scientific research alone may not be enough to sway public perception of the risks of re-introducing fire to landscapes. Arguments regarding the economics of reintroducing fire may be helpful. The rising costs of wildfire suppression stress federal budgets (Liang et al. 2008); the cost of using full suppression tactics on large fires can be in the billions of dollars. Arguments for suppression focus on catching fires when they are small and the costs can be limited (Ingalsbee 2017). This further exacerbates the problem by increasing the chances for more costly, large fires in the future. Fire use practices can be seen as a long-term investment to reduce the likelihood of additional large fires in the future and the costs associated with them (Houtman et al. 2013, Ingalsbee 2017). These funds can be reallocated to hazardous fuels mitigation work and suppression efforts in the wildland urban interface where human lives and private property are at the most risk.

Cognitive dissonance is unacceptable as a scientific community; we see that our current practices are leading to more problems in the future. For new management strategies to be accepted, continued scientific research in fire ecology needs to be pursued. There is currently an incomplete understanding of the role of fire in our landscapes (He et al. 2019). Research is needed to better understand the role of fire regimes in different landscapes and how it promotes biodiversity. Increasing our knowledge will allow land managers to make scientifically informed management decisions that to the best of our knowledge will provide beneficial ecological services to our landscapes. This knowledge needs to be shared with audiences outside the scientific and management communities. The public needs to understand fires serve a crucial role in the landscape and we must learn to live with them. Without adequate transfer of knowledge, progress will be slowed by public perceptions regarding fire that influence policy and management action. The scientific community and management agencies have an ethical obligation to educate the public and policy makers. Current practices are counterproductive and leading us down a slippery slope. If no action, or insufficient action is taken to steer the direction of future management practices, the responsibility for the outcomes falls on those who knew yet did nothing.

5. Mining

5a. Firm Mining Regulations Necessary to Support Critical Mining Practice

Megan Deming

Mining is oftentimes a controversial subject with an overabundance of varying opinions. There are countless downsides to this broken but necessary system, including negative effects on underserved communities, environmental degradation, impacts on cultural habits, and exploitation of resources and the workforce. However, mining is a practice that will forever be unavoidable in order to continue the development of new technologies, maintain the world's current standards of living, and economically support both developing and developed countries.

Mining is absolutely crucial to the world's growth; in order to progress mechanically, developers require the use of mined materials. Emerging technologies, such as sustainable power, renewable energy, electric vehicles, advanced engineering, and commercial space travel all depend on an increased source of the mined materials that the world already depends on (Minerals Education Coalition, 2019). Mining is also necessary to maintain society's current standards of living. Mined materials are needed to construct roads and hospitals, build automobiles, make computers and satellites, generate electricity, and provide many other goods and services that consumers enjoy (National Resource Council, 2002).

Not only does mining provide material goods, but it allows countries to be economically stable. The Bureau of Labor Statistics in the U.S. Department of Commerce estimates that the number of people directly employed in metal mining is about 45,000, in coal about 80,000, and in industrial minerals about 114,000 (U.S Department of Labor, 2000). However, these stats solely reflect the United States; many more individuals are employed worldwide. Many of these individuals would not be able to support themselves or their families without this career; mining brings many jobs to areas that would otherwise have very few employment opportunities. Another economic benefit for mining communities is the taxes that it brings to the area. These taxes are able to provide payment for hospitals, schools, and public facilities.

While mining oftentimes has a negative connotation, it is not something that can simply be erased from our developing world. In order to support economies and emerging technologies around the globe, we must support the mining industry rather than shun it.

Background Regulations

The only existing safety regulations on environmental and occupational regulations in the mining industry are those enforced by national and state governments. These laws differ between countries and are often susceptible to corruption; many companies find ways to evade these legal bindings through lobbying or bribing (MIT, 2018). Without international mining environmental and occupational regulations, it is much more difficult to prevent the contamination of water, air, and soil and also to prevent mining accidents.

However, the United States has implemented many policies to protect the environment. The National Environmental Policy Act (NEPA) was passed in 1969 and established the basic environmental policies for the nation. This defines processes for evaluating environmental consequences of federal decisions and actions, such as the permitting of new mine development on federal lands (AGI, 2019). Another vital act, the Resource Conservation and Recovery Act (RCRA), was passed in 1976 and focuses on the prevention of hazardous waste being released into the environment by providing management from the generation of these materials to their disposal (AGI, 2019). Without these regulations, it would be very difficult to enforce other, more specific environmental policies.

The United States has also implemented regulations specific to the resources that need to be protected, such as water and air. The Clean Air Act (CAA) authorizes regulations to address any airborne pollution that may be hazardous to human health or natural resources while the Clean Water Act (CWA) authorizes regulations that cover discharges of pollutants into the surface waters of the nation (AGI, 2019). These acts directly protect resources that are necessary for human survival.

Not only are there regulations that establish basic environmental policies and protect necessary resources, but there are also acts that regulate application of hazardous materials and the cleanup of those materials. The Toxic Substances Control Act (TSCA) focuses on the development and application of chemicals and other hazardous materials, such as those used in the processing of ore or ore concentrates (AGI, 2019). The cleanup of sites is addressed in the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA); this enables the government to clean up any site where there is an unremedied release of a hazardous substance. This includes mining, milling, and smelter wastes, which are currently excluded from regulations under RCRA. Regulators have the authority to use special funds, undertake emergency responses, and hold all contributors liable for cleanup costs (AGI, 2019). These regulations ensure that even after operations are complete, companies can still be held responsible for their misconduct.

Although the United States and many other countries have many regulations in place to protect both the environment and workers' rights, some countries that we often trade mined goods with do not have these same regulations. The lack of regulations continues to cause social and economic tension in the developing world. Inaction will only allow more strain on the welfare of the environment as well as the welfare of the miners themselves.

Sustainable Development Goals

Figure 5.1: United Nation's goals for sustainable development. The goals outlined in grey (goals 7-13) are goals that can be applicable to mining practices.

The United Nations have created a call-to-action for all member countries in global partnership to encourage peace and prosperity for people and the planet. This call-to-action includes 17 goals (figure 5.1) of ending poverty and other deprivations; these strategies aim to improve health and education, reduce inequality, and spur economic growth—all while tackling climate change and working to preserve the world's oceans and forests (United Nations, 2018). Many of these goals can be applied to mining practices as guidelines of how mining should be regulated globally.

These goals support the premise that mining is a necessary practice. Goal 7 states that there should be access to affordable, reliable, sustainable, and modern energy for all. While access to electricity across the globe has begun to accelerate, 800 million people remain without electricity (United Nations, 2018). With access to mining, these countries can generate their own electricity. However, even if developing countries rely on renewable energies, those technologies also require mined resources. This will be discussed further in chapter 6.

Many of these goals address economic stability, which can be supported by the mining industry when mining is done in an economically sustainable way. Goals 8, 9, and 10 focus specifically on economic growth. As stated by goal 8, inclusive and sustainable economic growth can drive progress, which is needed to increase employment opportunities, reduce informal employment, and promote safe and secure working environments for all (United Nations, 2018). This goal will set the stage for safe, fair employment which is often overlooked in unregulated countries. Goal 9 focuses on building resilient economic infrastructure while promoting inclusive and sustainable industrialization while goal 10 aims to reduce inequality within and among countries (United Nations, 2018). Mining can address both of these goals to economically support countries by providing jobs that will result in sustainable industrialization and will allow these countries to rise out of poverty, minimizing inequality between countries.

The United Nations call-to-action emphasizes the importance of economic growth through environmentally sustainable means. Goals 11, 12, and 13 underscore the importance of combating climate change while not impeding the progress of the country. Mining practices should follow these same standards, contributing as little as possible to any pollution and being sure to have solid restoration plans in place to diminish environmental impacts.

These goals provide a framework for a structure of international mining practices. While individual countries do have a solid start when it comes to regulations protecting the environment and the people, further measures are needed to ensure this protection blankets the entire globe.

5b. Environmental effects of mining

Axel Barth

Mining plays a huge role in both the global economy and energy consumption. In 2012, the total revenue of the top forty mining companies worldwide was 731 billion U.S. dollars. The annual revenue from mining dropped to $496 billion in 2014, and then slowly increased again to $683 billion in 2018 (PwC 2019). Since the 1800s, mining has been used to extract coal and crude oil from the Earth. In 2017, crude oil and coal made up 63% of the total global energy consumption, while traditional biofuels, natural gas, hydropower, nuclear, wind, solar, and other renewables made up 37% of the total global energy consumption (Ritchie 2014). While many people are advocating for less mining and the transition to renewable energy sources, it's impossible to altogether erase mining without a drastic collapse in both the global economy and energy use.

Although mining provides many services to humanity, there are also many adverse implications for the health of environments. Around the world, countries are creating laws and regulations to keep mining companies accountable for restoring ecosystems back to their original state. Through informing mining companies of the potential opportunities to reduce their impact on the environment, as well as electing officials who enforce regulations and laws that promote eco-friendly practices, the impacts of mining on the ecosystem should be reduced tremendously.

Mines' Effects on the Environment

The soil, water, and air surrounding a mine are often polluted by heavy metals and other contaminants, leading to a loss of biodiversity. Soil erosion, soil pollution, and sinkholes are often the latter effects caused by mining on the terrain. A study done at an abandoned barium mine in the Sierra de Guadarrama, Madrid, Spain concluded that the heavy metals and high pH in the soil, caused by the mine, led to a decline in biodiversity. This was determined using the Shannon index and species richness models (Hernandez 2008). Native species were more negatively affected, while ruderals and invasive species were less affected. The specific elements in the soil that had the greatest effect on plant biodiversity were zinc, cadmium, and copper (Hernandez 2008).

Aquatic systems, such as streams, are also affected by mining activities. Soil erosion releases sediments that can smother streambeds (Chepkemoi 2017). These sediment loads have the potential to smother aquatic life living in these areas. Mining geologic formations containing pyrite often leads to acid mine drainage, which also tends to have a negative effect on aquatic flora and fauna. The process of acid mine drainage occurs when water and air chemically react with exposed sulfur-bearing rocks. Pyrite is one of the most common sulfur-bearing rocks exposed during mining. This runoff releases sulfuric acid and dissolved iron into the water. Ferrous iron causes an imbalance in oxygen levels, lowered pH, and ferric oxide particles suspended in the water. Other metals such as copper, lead, and mercury can also dissolve into the water (Stumm et al. 1960). These dissolved metals can pose a threat to aquatic species. Oftentimes the metals either create toxicity levels too high for the flora and fauna to survive, or they kill the species through other means, such as clogging a fish's gills.

Currently, mining companies around the world are looking to mine in pristine areas that may suffer from the consequences of mining, such as acid mine drainage. One of these areas includes the Boundary Waters in northeastern Minnesota, which is threatened by sulfide-ore copper mining. This specific type of mining often contaminates water through the process of acid-mine drainage, which ultimately harms aquatic organisms. A study looked at fourteen sulfide ore copper mines in the United States. These sites make up 89% of the total copper production in the US. They found that all the mines had either a pipeline spill or some other release of toxins (Garwin 2015). It is important to maintain a healthy environment in the Boundary Waters because it is not only economically important, being America's most visited wilderness area, it also 1.1 million acres of clean streams and forests (Garwin 2015). There are over 1,200 miles of interconnected waterways within the Boundary Waters, so a release of toxic chemicals could have a devastating effect on the entirety of the ecosystem, rather than just the site of release. Ruining this ecosystem through mining would be detrimental to this nature reserve.

Generally, the wind around mines picks up particles that are toxic to native plants and animals and sweeps them across the landscape. These toxic particles often contain harsh chemicals such as: sulfur dioxide, nitrogen dioxide, and ozone (Pandey et al. 2014). These air pollutants can affect the physiological processes in plants by damaging their leaf cuticles which decreases stomatal conductance. This leads to a decline in photosynthesis, leaf longevity, and its ability to allocate carbon (Winner 2003).

The soil, water, and air contaminated by irresponsible mining practices leads to a loss in the biodiversity of native flora and fauna. It is important to have the native species for the health of the ecosystem, otherwise it becomes unstable. Maintaining biodiversity is beneficial in protecting against soil erosion, defending from natural disasters, reducing the risk of climate change, recycling nutrients, pollinating, controlling pollutants, and providing other services (Pandey et al. 2014).

Regulations

Countries around the globe have different government agencies and organizations that enforce separate environmental regulations and laws on mining companies. South Africa and China have some of the largest mining industries in the world and administer laws differently to each other as well as to the United States.

In the United States, the Environmental Protections Agency (EPA) is responsible for keeping mining companies accountable for following regulations that will reduce the impact of mining on the surrounding environment. Some of these laws include the Clean Air Act (CAA), passed in 1970, which addresses negative implications to human health and natural resources caused by airborne pollutants (What are… 2019), and the Clean Water Act (CWA), passed in 1977, which covers the proper disposal of waters by mining companies (What are… 2019). Although many environmental regulations in the United States are setup to help ecosystems, some have been revised or changed in order to allow mining companies to cut corners.

In 2002, under section 404 of the Clean Water Act, a statement was released allowing mining companies to use their waste as fill material (Ecological Impacts... 2017), meaning that mining companies could fill in expanses of land with the waste produced on site, such as rubble. Also, the Surface Mining and Reclamation Act of 1977 allows mining companies to restore once forested lands with non-native grasses rather than remediating them back to their original state (Ecological Impacts... 2017). This is often seen in the Appalachian mountain range where over 500 mountains have undergone the harsh effects of mountaintop removal. Much of this land is no longer forested with the native deciduous and coniferous trees once seen in that area but is rather filled with nonnative grasses (Ecological Impacts… 2017).

The Minister of Environmental Affairs is the official in South Africa who implements laws on mining companies. Some of these regulations include the Petroleum Resources

Development Act (MPRDA), the National Environmental Management Act (NEMA), and the Financial Provision Regulations (FP Regulations). In November of 2015, the FP Regulations added the requirement that mining companies must lay out a financial budget in order to remediate lands that were used for mining, and to clean any foreseen contaminants on site (Mining 2020… nd).

In China, the Ministry of Ecology and Environment carries out laws that promote the health of the ecosystem surrounding a mining area. One of these regulations includes the Mineral Resources Law (MRL) which oversees mining rights, restrictions, and registration (Mining 2020 nd).

Laws around the world are continually changing depending on the priorities of the country. The environment is not always a top priority for mining companies when creating a budget. It is important for citizens and government officials to be aware of the potential irreversible consequences that may take place if measures are not undergone to restore and protect ecosystems containing native populations of plants and animals. Also, many current laws are not necessarily well defined and may benefit from revisions.

Suggestions

Biodiversity is an incredibly important aspect of the Earth to preserve as more mining operations are popping up around the globe. Since regulations may be broad and unclear, it is important to consider other factors that may be woven into pre-existing laws to improve the health of the environment.

Pumping groundwater instead of surface water for mining contributes to the health of the stream and the aquatic organisms established in that area. Recycling materials, such as grey water for the use of washing equipment and staff toilets, not only helps the environment but also has the potential to save the company money (How Can Mining… 2018). Similar to the Financial Provision Regulations mentioned previously in South Africa, a material flow analysis could be used annually to track the flow of natural resources through the processes of extraction, production, fabrication, and disposal to make sure the yearly budget accounts for any mishaps occurring in those processes that could be detrimental to the surrounding ecosystem (Laner 1970). These material flow analyses also allow companies to account for unused materials that may be recycled and used once again, saving materials and money (Figure 5.2). Lastly, the current laws could be more detailed in how mining companies need to have remediation plans that will restore the environment back to its original habitat with native flora and fauna.

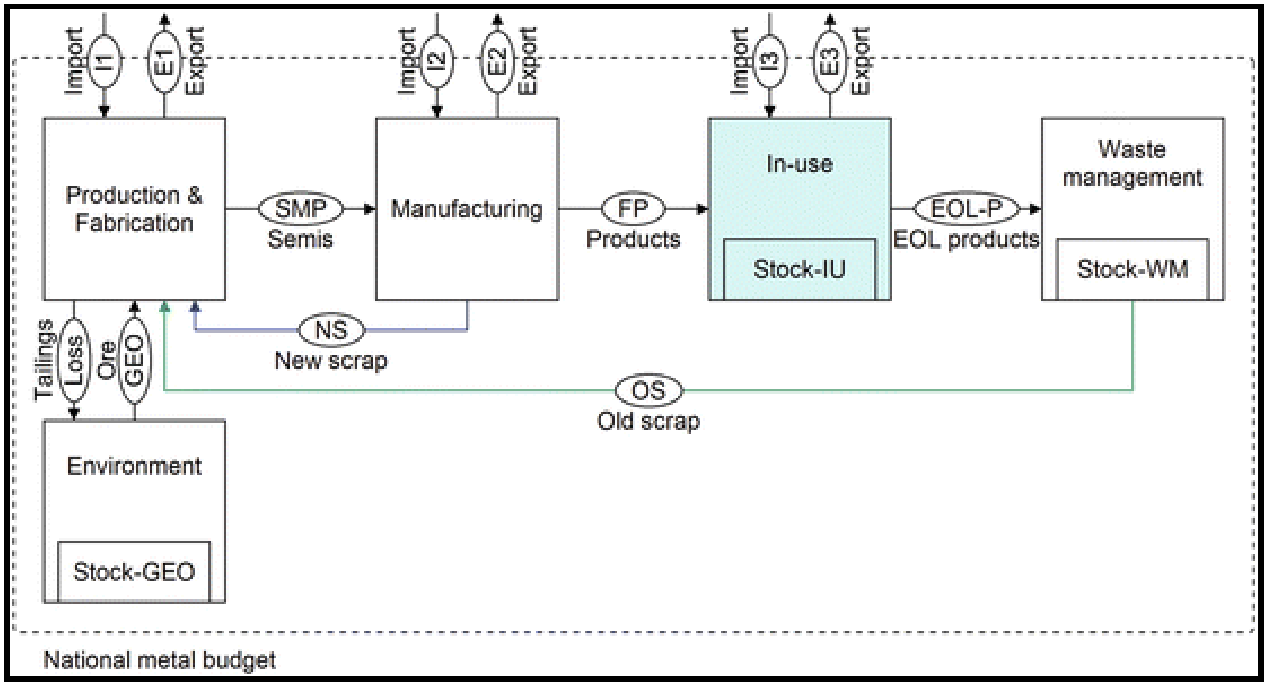


Figure 5.2. Simplified Material Flow Analysis (Laner 1970).

5c. IF NOT THERE, WHERE?
Joseph Lazarus
Losing Remote Wilderness to the Anthropocene.

"Its science's goal is to find out how the world works, to seek what regularities there may be, to penetrate the connections of things—from subatomic particles, which may be the constituents of all matter, to living organisms, the human social community, and thence to the cosmos as a whole." -Carl Sagan

To the humans that call Bristol Bay home, salmon is everything. Every year, 50 million sockeye salmon and several other species of pacific salmon make a journey from the Pacific Ocean up into several rivers that drain into Bristol Bay. This great event is important both ecologically and socially for the remote communities of Alaska due to several reasons: economics, culture, and recreation. When these fish come home, indigenous people will celebrate their return, tourists will fly from across the globe to watch massive grizzly bears gorge themselves on the salmon, adventure seekers will take to the big rivers with a fly rod to catch memories they will cherish forever, and commercial fishermen will take to the Bering Sea to earn their keep for the upcoming year. These activities sustain a multi-billion dollar recreational and commercial industry that is under threat that humans have placed on this special place (SaveBristolBay… 2017). The Pebble mine, the largest mine ever proposed in North America is under review for permitting in the Bristol Bay watershed (SaveBristolBay… 2017). Scientists have gathered data on the proposed mine and community members have spoken that the Pebble Mine is the wrong mine in the wrong place. Allowing this mine to go forward would not only destabilize one of the last great anadromous fisheries left on the planet but also ruin the cultural traditions and livelihoods of many locals (BBNC…2019). On the other hand, if humanity doesn't slow down its consumption of these resources not only will this mine go through but many other mines will be created globally. So the question humanity must ask itself is if not here, where?

South West Alaska

Southwest Alaska is a spectacular environment shaped by a glacial past with a diverse array of plant and animal life. The Pebble deposit sits on a landscape dominated by glaciation, with wide glaciated valleys and permafrost soils. Surface waters are abundant here, sustaining a broad category of seasonal and resident life. Lake Iliamna, Lake Clark, and six major river systems comprise a major area in Bristol Bay. The proposed pebble mine sits in the Nushagak River drainage, however through groundwater is also linked to the Talarik River (Chambers 2018). All five species of anadromous Pacific salmon call these drainages home: King salmon, Sockeye salmon, Chum salmon, Pink Salmon, and Coho salmon. Several other species of fish are residents in the area, the most common of them being the Dolly Varden and Arctic Grayling. Caribou migrate through the location of the Pebble deposit seasonally after spending time in their calving grounds. Grizzly bears, black bears, and wolves also frequent the area near the Pebble deposit and all of Southwest Alaska (Pebble Mine Report… 2012). The area is home to several different vegetation communities: alpine tundra, shrublands, wetlands, scrub communities, and areas of mixed broadleaf and spruce trees (McCoy 2019). The diversity of Southwest Alaska is incredible for its geographic location but the king of life in this area is the salmon.

In 2010, over 40 million sockeye salmon returned to Bristol bay. Although all five species make the return into Bristol Bay’s waters, sockeye are the most prolific and almost 50% of all commercial sales of sockeye salmon come from Bristol Bay (Cheyette 2018). When salmon return they bring 164 metric tons of phosphorous are input back into the waterways of Bristol Bay after their return and inevitable deaths. This input along with everything else the salmon bring will go on to support the ecosystem and help tree's grow, feed bears and support other ecosystem functions and then the salmon cycle will repeat itself year after year. So while this is important ecologically this return is important socially for the commercial fishermen that make their livings fishing for these anadromous fish and for the three different native tribes that call Bristol Bay home (Pebble Mine Report… 2012).

The Athabascans, Aluetians, and Eskimos all sustain their families and culture off of the salmon that return to Bristol bay. With subsistence lifestyles that depend on salmon returning, a destabilization of the native's food source would destabilize their way of life. Economically, a loss of this resource could lead the way into a total collapse of the communities in Bristol Bay, because most jobs in Bristol Bay come from commercial fishing commercial fishing in Bristol Bay is the economic foundation of this area (Our People…2018). This fishery is the most valuable salmon fishery left on the planet where salmon from these watersheds produce $1.5 Billion dollars annually. Locally, Bristol Bay provides 14,000 jobs, nationally Bristol Bay sustains 20,000 jobs (Cheyette 2018). Putting a copper, gold, and molybdenum mine in this landscape fundamentally jeopardizes this area's economic prosperity and cultural identity.

The Mine

The Pebble Project is a proposed copper, gold, and molybdenum mine owned by Northern Dynasty. The mine site is proposed to be 5.3 square miles with 65 miles of road and two ferry terminals on the east and west side of Lake Iliamna that will require an 18-mile ice breaking ferry ride between the two ports, as well as a gas fired power plant to maintain operations and a gas pipeline that runs across Cook Inlet to power the plant (figure 5.3).

This will be an open pit mine where sediments are taken out of the pit and crushed, then the crushed material will be milled and then put into a tank where the retrievable ore will sink and byproduct will float. This by product will then be stored in a bulk tailings facility. The

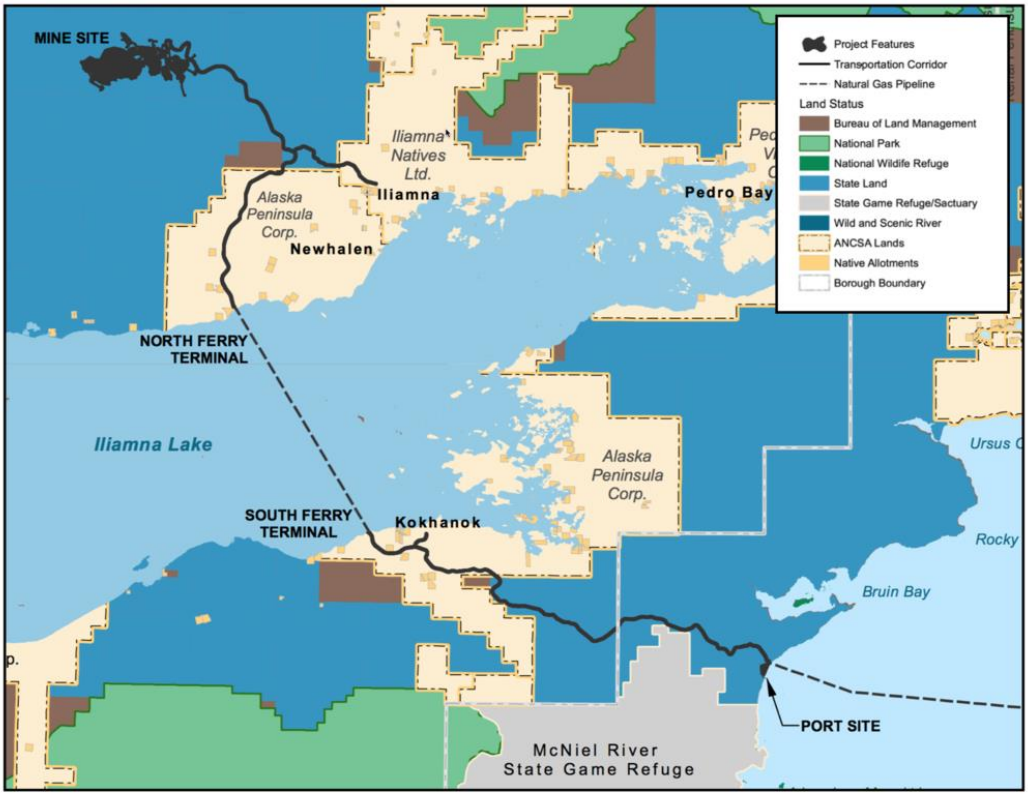


Figure 5.3. Map of the transportation corridor, natural gas pipeline, and mine site across Cook inlet and Iliamna lake.

retrievable ore will be ground again, and the toxic grinding byproduct will be stored in a lined tailing facility, while the retrievable ore will be processed and shipped for refining (figure 5.4) (Pebble Partnership 2019).

Northern Dynasty expects to remove 1.44 billion tons of ore over the 20-year life expectancy of the mine (McCoy 2019). There are an estimated 107 million ounces of gold (worth approximately 156 billion US dollars), 80 billion pounds of copper, and ~5 billion pounds of molybdenum found within the pebble deposit (McCoy 2019).

Acid Mine Drainage and the Pebble Project

Even though projects across the globe have revolutionized the way mining is conducted, risk factors are still present (Chambers and Zamzow 2019). Starting with the nature of this deposit. the Pebble deposit is rich in sulfides and after extraction the byproducts of extraction contain high concentrations of these sulfides (otherwise known as “pyritic tailings”) if left exposed to molecular oxygen or ferric iron they release metals and acid into the surrounding area spontaneously. Therefore, it is common practice to store these pyritic tailings in lined sub-

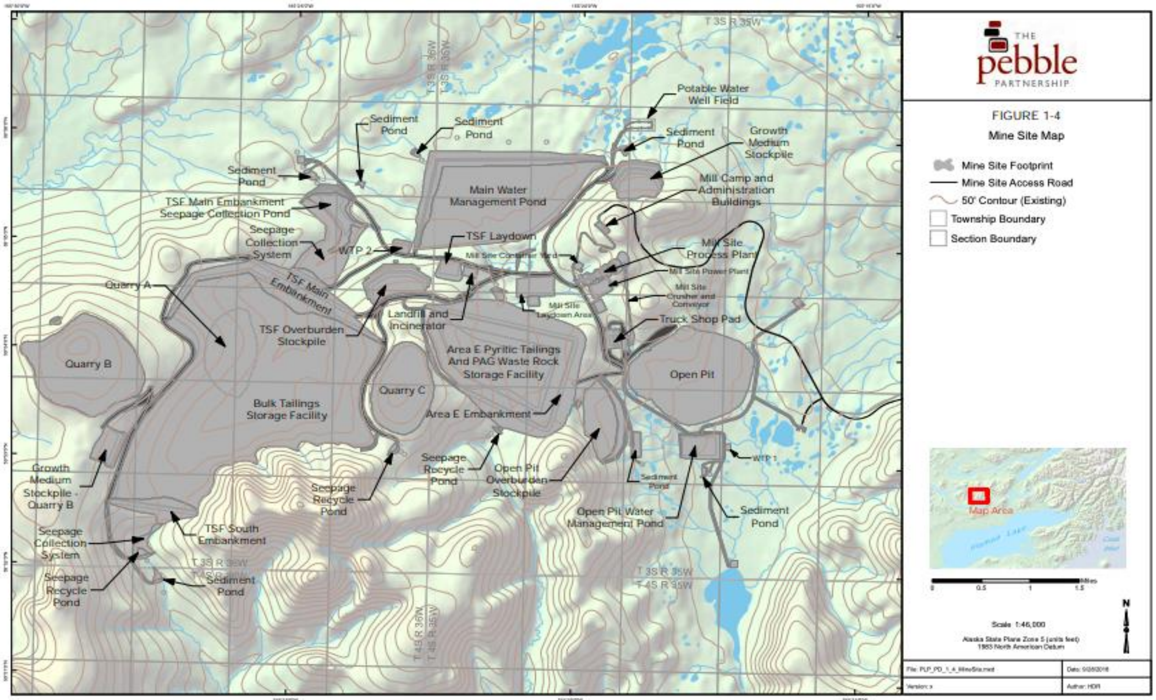


Figure 5. 4. The Pebble Partnership proposed mine site facilities map.

aqueous storage facilities to limit exposure to oxygen (Garcia et al. 2004). These underwater storage facilities are ticking time bombs that carry the destructive force to render entire watersheds negligible of life. Through the late 20th century into the early 21st century scientists have seen more of these tailings facilities fail (Figure 5.5) and in their failures plant communities die, animal populations die, and groundwater is contaminated to a state not fit for consumption by anything and only the most extreme microbial communities can call these toxic environments home (Garcia et al. 2004). This is the biggest cause for concern at the Pebble mine, due to Southwest Alaska's unique environment and economic background a mine like this is just too risky to be put on this landscape.

While pyritic tailings are stored underwater, a dam or an embankment keeps them in place. The Pebble project proposes storing the pyritic tailings in a temporary facility and when the mine shuts down operations, pump them back into the open pit for long term storage underwater. Northern Dynasty claims that after they are pumped back into the pit for long term storage, the pyritic tailings will be no longer be a threat to the environment and downstream

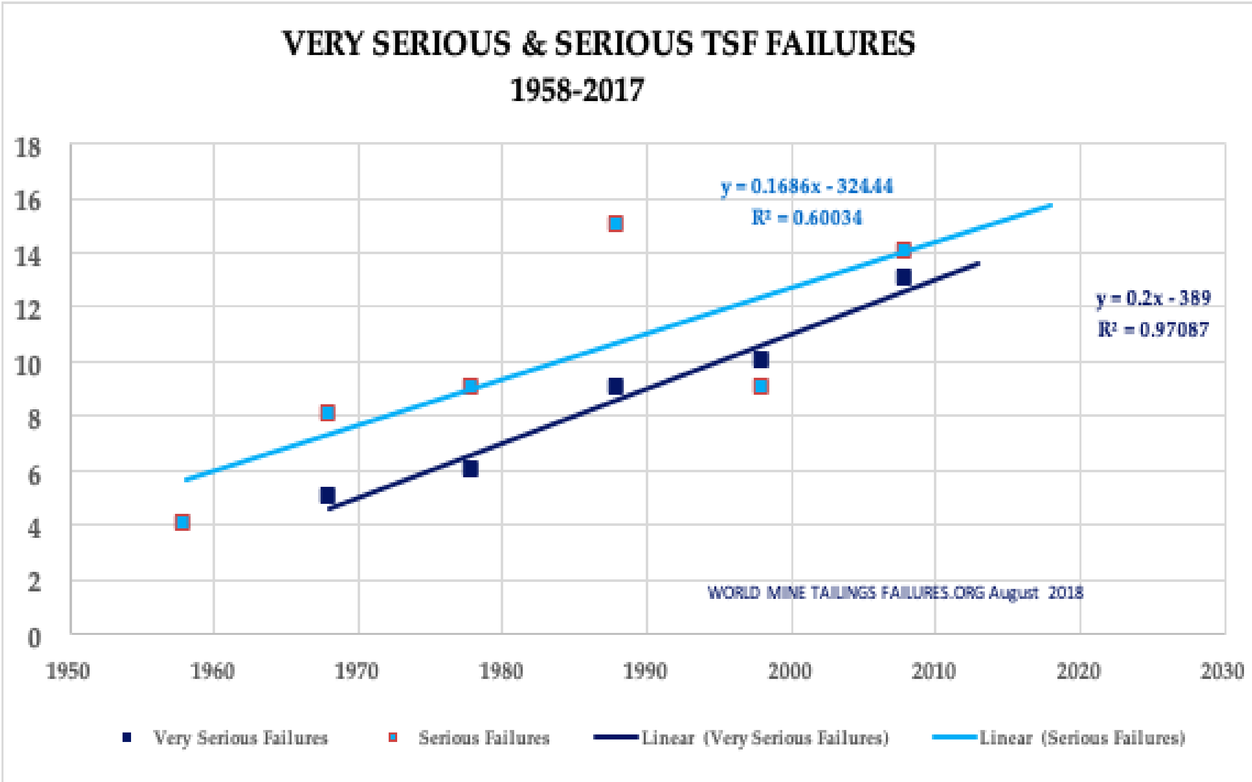


Figure 5.5 Tailings storage facility failures across 360 mines globally from late 1950's to early 2000's. Courtesy of the Center for science in Public Participation.

habitat. However. it is less clear whether the short term storage will be of environmental concern. Northern Dynasty proposes another pond where the pyritic tailings will be stored short term. This will be enclosed by a large embankment and then decommissioned when the mine stops operations. During this process from start to finish, moving these toxic materials around exposes too many areas where an accident could happen that leads into a catastrophe. Pouring a massive quantity of copper and accompanying significant changes to pH in a certain waterbody will disrupt the function of that system.

As copper is the predominant metal found in the deposit, it's acute or chronic release into the waterway will have devastating consequences for the fish (Woody and O'Neal 2012). $Cu2_{+}$ (cupric ions) are the most toxic form of copper, because $Cu2_{+}$ is dissolved into the water and is highly bioavailable (Woody and O'Neal 2012). Exposing fish to anywhere between 10-20ppb ("parts per billion" or micrograms per liter) of copper for will result in death (Woody and O'Neal 2012).

Copper availability in the water depends on whether the water is "hard" or "soft" and what are the other elements (referred to as cations or anions) available in the waterway and the pH of the water. Copper is most toxic under environmental conditions where: the water is soft (water lacking cations like calcium Ca^{2+} and magnesium Mg^{2+}), the pH in the water is less than 6 (acid conditions), and dissolved organic carbon (DOC) is low in the waterbody (DOC will bind to cupric ions and transform them into something less toxic) (Woody and O'Neal 2012). Water tested in other mine claims in the Iliamna area have shown that the water is very soft with low concentrations of DOC (Woody and O'Neal 2012). Giving way to the uncomfortable reality of this mine: If some uncontrollable event occurs and a tailings pond is allowed to leach its toxic constituents into the waterbody, a devastatingly lethal cocktail of conditions will lead to the complete death of an entire waterbody of fish. Even if copper is released from the mine in quantities small enough to not kill fish, it will have effects up and down the local food chain, disrupting local processes and potentially leading to a trophic cascade resulting in the deaths of megafauna in the area that rely on the salmon (Woody and O'Neal 2012).

Conclusion

Environmentally the Pebble project is a disaster. Economically, the risks of the project outweigh the rewards. The locals of Bristol Bay, scientists, and the general public have made it pretty clear they do not want the Pebble Project to move forward. Yet a government hell-bent on permitting this mine thinks it should move forward. Nationally, the Bristol Bay fishery provides more than the Pebble mine ever can or will. The fishery sustains a cultural significance to thousands on Native Alaskans going back 10,000 years, it supports 50% of sockeye salmon sold globally, and it sustains an amazing ecological phenomena that is constantly being put under threat by humanities consumption problem. The stakeholders on this project have everything to lose, while only a few top people at Northern Dynasty have things to gain. Do these environmental risks outweigh the financial rewards of a project like this. While other mines in North America have found ways to become good neighbors to stakeholders near them, why is it that Pebble has only received more opposition as the project has carried on (Pebble Mine…2019, Good Neighbor…2019).

Right now, humanity's consumption is threatening the unique ecology and culture of the Bristol Bay region. While the greater question exists: "how can humanity reduce and limit its consumptive ways." The people that live in Bristol Bay have made it clear they do not want the Pebble mine, and thousands of people have made statements to the U.S. Army Corps of Engineers about the mine. While it is abundantly clear how disastrous a mine like Pebble could be from the loss of great economic value to the loss of cultural identity there is a serious question that everyone who consumes goods in the 21st century needs to ask themselves. "If I am not ok with this mine here and I am a consumer of goods made in this current age defined by great technological advances, where am I ok with a mine? If I am not ok with mining anywhere is it possible for me to completely limit my uses of technologies that are products of mining?" If consumers are not going to limit their consumption, are they ok with sending mines to foreign countries with potentially no environmental regulations? Would a mine be better suited in the United States where there are strict environmental regulations in place and where lots of safeguards are in place to prevent severe catastrophes like what happened in Butte Montana. There are a lot of questions that need to be addressed moving forward but to many it is clear, the Pebble project is the wrong mine in the wrong place and even though more questions are left to be answered the earth does not need to take any more ecological losses in an age defined by them.

5d. The Science of Cobalt Mining: Socioeconomic Consequences

Jack Paloucek

Cobalt (Co) is an essential element in today's booming economy, especially in the United States and China. With the enhancement of technology and green energy, many processes are being used to efficiently store power, specifically with everyday devices like cell phones, computers, and electric vehicles. Because of that, demand has tripled between the year 2000 and 2010 and is only going to become more prevalent with the advancement of technology (Tsurukawa et al. 2011). Artisanal and small-scale miners are extracting common cobalt ore in South-Eastern Congo. This region in the Democratic Republic of Congo (DRC) is responsible for one of the world's largest cobalt reserves and will be the focus of this paper. This paper will also highlight the mining process for cobalt, why consumers need it, exploitation of resources, the cobalt market, the consequences of production, and impact on society.

Cobalt is widely used in chemical applications, mostly for rechargeable batteries and catalysts, the demand for both is expected to increase (Cobalt Facts…2016). It is also used in super alloys capable of withstanding high temperatures, which are used in jet engines, as well as aerospace defense applications. It is mostly used in lithium ion batteries, for mobile device batteries, but more recent application is rechargeable batteries for electric cars. Rechargeable batteries for cars are the leading use of cobalt on a worldwide basis (Cobalt Facts…2016). This demand will increase as the prevalence of electric vehicles increases. Overall, a 68% increase in world consumption of cobalt is forecast between 2015 and 2025 (Spencer 2016). A report from Adamas Intelligence shows that the use of electric vehicles increased 81% from 2018 to 7200 tons in 2019. The increases in world cobalt production from 2000 to 2015, which is mainly due to the advancement of technology (Figure 5.6).

However, the price of cobalt and the market is more fragile than the other major metal markets, mostly being influenced by the prices of nickel and copper, where most of the cobalt deposits are contained (Minerals Yearbook…2008). This makes it difficult to increase cobalt production as it is limited by the demand of these meals. Other forms of cobalt production take place in nickel and copper mining operations due to cobalt being contained in the nickel and copper ores. This combination of minerals and high concentrations of copper, nickel, and cobalt is located in the DRC.

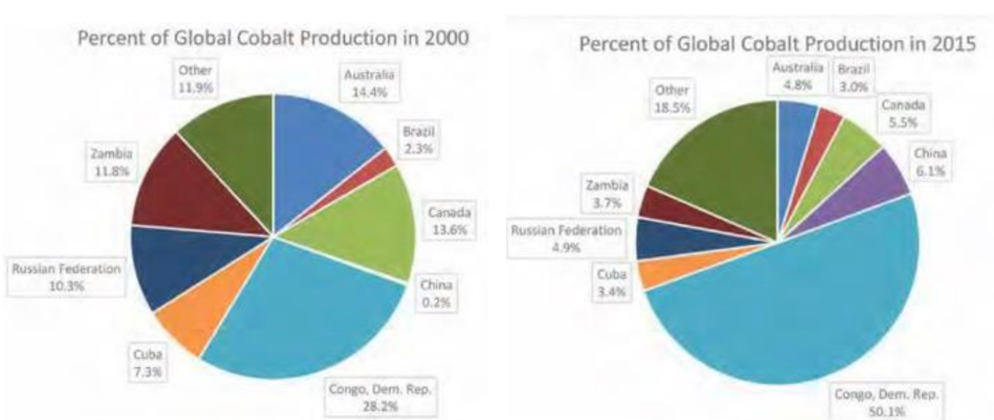


Figure 5.6: Distribution of world cobalt mine production (Tsurukawa et al. 2011).

Exploitation of resources

The large cobalt concentration area in South-Eastern Congo is essential for the contribution to cobalt ore and materials needed for advances in technology. As the world transitions to electric vehicles and increases production of smartphones and laptops, the demand for this element will continue to skyrocket. In 2010, cobalt from this area supplied half of the global cobalt primary production (Figure 5.6), and during the last decade, 60-90% of this cobalt was from artisanal mining (Tsurukawa et al. 2011). Artisanal Mining is the small scale, unregulated mining that has been seen to have negative effects on the community and surrounding environments.

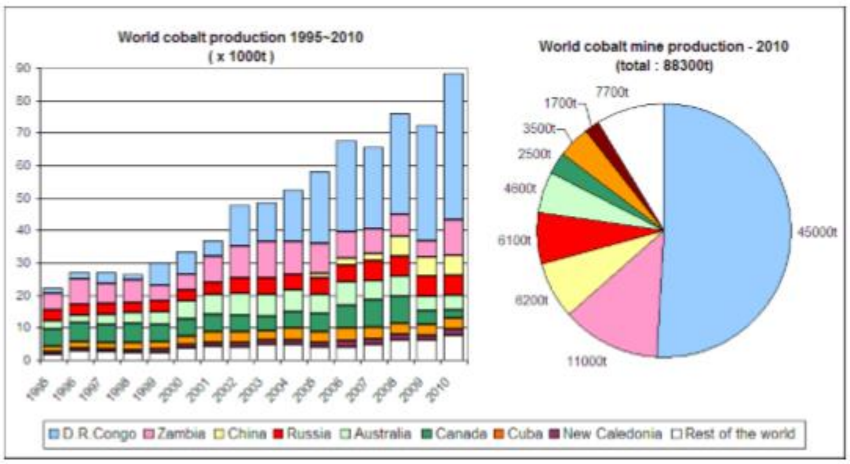


Figure 5.7: Repartition of world land-based cobalt production from 1995-2010. Source: USGS 1995-2010

Supply and Demand Industry

Many of the stakeholders such as China, Japan, and the United States have different interests regarding the portrayal of information about cobalt mining. Most stakeholders sway their information to benefit their stake, which presents issues on reliability of data. For example, tech companies may fail to comment on where they acquired the cobalt, while local officials might underestimate the number of mining zones to lessen the amount of taxes that need to be paid. This cobalt market is filled with lucrative operations that have found loopholes for management and production, the result being a negative effect on local communities, such as black market operations and exploitation of poverty. These loopholes are present in all forms in the cobalt market, from child labor in mining communities to black market purchases from China that undercut the big tech companies and provide a higher percentage of pay to locals.

The main consumers of cobalt are the United States and China, with China being the world leader in cobalt refining. China's cobalt refining capacity expanded from 3% of world capacity in 2000, to 40% of world capacity in 2015 (Shedd 2017). This increase was mostly in response to the increase in cobalt use by the battery industry. The refineries present in China import most of their cobalt ore and concentrate from the DRC. With greater cobalt consumption and new battery applications being introduced, China increased their cobalt investment in 2015 as their country has the highest battery production in the world. Conversely, the United States is a leading consumer of cobalt based materials and products. The U.S. mines less than 1% of the world cobalt production, however, the U.S. consumes an estimated 10% of the world refined cobalt supply (Annual Cobalt…2017).

Socioeconomic and Health Consequences

Smaller artisanal mines in the DRC are the main concern because they are employing crude, labor-intensive mining methods, in especially dangerous working conditions. These artisanal mines contribute an estimated 60 and 90% to the share of cobalt production in the DRC (Tsurukawa et al. 2011). Artisanal mines expose workers and communities to contamination that affects human health; the highest health risk related to this is soil ingestion of copper and cobalt in the smelting area (Ettler et al. 2012). Additionally, the urinary Co concentrations found in this population living within a 10km radius of mine related activities are the highest ever reported for a general population (Banza et al. 2009). Less than 10% of the artisanal miners have knowledge of common mining regulations and conditions (Artisanal Mining…2010). This lack of education for miners presents safety issues for the mines and mainly the people. Specifically, the lack of education leads to poor sanitation in the camps, where the water used in mining is commonly drunk by the community. As a consequence, the general state of health among miners' communities in this region is poor, showing trends of reduced life-expectancy, higher infant mortality rate, higher prevalence rate of HIV, diarrhea, hepatitis, etc. (Tsurukawa et al. 2011).

Socioeconomic conflicts are prevalent in the DRC between the small scale artisanal miners and the private mining companies in the region, where they are confronted by the local artisanal miners operating on the private land. Different strategies have to be made to mitigate conflict, including confrontation with security forces, seizing the artisanal mine production, compensation for vacated area, or allowing the company to continue mining. Political instability and history of conflicts in the DRC present issues with investment because of the high-risk business environment (CPIA Transparency…2015). These conflicts are directly affecting international cobalt supply; this is because adequate governance is necessary to attract investors, uphold laws and regulations, and to maintain mining physical and business infrastructure. Lack of education and poverty of the region leads to side effects for the mining process. The ability to support a family in such conditions with low wages being earned, means that the whole family is likely to participate, regardless of age. In this region, 28% of the workforce, between 19,000 and 30,000 miners are children under the age of 15, and some of them are as young as 6 years old. These young children mostly carry out light tasks of mining, like sorting, washing and sieving ores, but are even forced to dig in the narrow tunnels where adults can't fit (Artisanal Mining…2010). Since child and slave labor have been reported in the artisanal mines in the DRC, tech companies seeking the ethical supply chain are facing shortages of cobalt. Despite all of these socioeconomic and health issues related to cobalt mining, it is essential for the global market and local communities where this is the only source of income.

Conclusion

Most artisanal mining is unregulated and can be associated with negative social and environmental impacts (Tsurukawa et al. 2011). As industrial consumers become more concerned with ethical and responsible sourcing of their raw materials, dependence on the unregulated artisanal mined cobalt becomes less desirable. Despite all the negative impacts, artisanal cobalt mining plays a crucial role in the socio-economic stability in the DRC. Even though this form of mining is labor intensive, it does provide income to a significant portion of the population. Artisanal cobalt mining has the potential to alleviate poverty and trigger sustainable development in this region because that mining can be taken up by unskilled workers, and does not require significant investments (Tsurukawa et al. 2011). Therefore, it is recommended that international efforts should focus on strengthening artisanal mining practices rather than introducing initiatives aiming to restrict or ban cobalt supply from artisanal sources. The strengthening of the artisanal mining processes will promote the local communities' economy and continue to provide for the global demand of cobalt. Black markets and corruption in this industry will persist, but with better mining regulations that support the ethical supply chain of cobalt, the industry will thrive and keep producing cobalt for global demand. With tighter regulations on the ethical applications of artisanal cobalt mining, child labor can be mitigated, wages earned for locals can increase, and safety of mining practices can be controlled.

5e. Ethics of resource extraction: protecting the environment, local communities and addressing poverty to meet global demands of mined resources

Stacey Robbins

As the global community confronts climate change by shifting away from fossil fuels and moves towards a heavier reliance on "clean energies," mining plays a foundational role in supplying materials required for these technologies. Adoption of low-carbon energy systems requires much more metal-intensive technologies than current energy systems (Koning et al. 2018), and the criticality of mined resources is best summarized by the British Geological Survey in the statement "if you can't grow it, you have to mine it." To produce clean energy through wind energy, for example, and to provide transportation with low-emission vehicles rather than combusting fossil fuels, a growing quantity of critical metals are required in the manufacturing process. Demands for these critical metals will disproportionately increase relative to more abundant and commonly mined metals, such as iron or copper (Bloodworth and Gunn 2012). For example, wind energy and electric vehicles rely heavily on the two rare earth elements dysprosium (Dy) and neodymium (Nd). These metals are co-mined or generated as a by-product from ore extractions focusing on the recovery of other metals (Alonso et al. 2012). The supply of these of rare earth metals has historically grown to meet demands, with rates as high as 12% increase when averaged over 5 years. However, Alonso et al. (2012) estimate that Nd and Dy will need to increase 700% and 2600% (respectively) to meet supply demands in the automotive industry and wind energy applications over the next 25 years to meet future demands. Mining is foundational not only to clean energy production and the automotive industry, but also for today's standards of living in many developed countries in the form of infrastructure and technology. To support the increasing world population and the growing middle-class resulting as poverty is decreased, mineral extraction cannot simply cease as a response to combat environmental issues. Environmental and social consequences resulting from poor management and lack of regulation therefore require immediate revision and improvements in terms of policy and technology to protect the environment and human health that motivated a transition to clean energies.

Resource deposits are unevenly distributed around the globe, and poorer countries often sell their resources in pursuit of economic growth only to move toward deeper poverty and instability, rather than prosperity (Bloodworth and Gunn 2012). To meet global demands, supply from resource pools in all countries will be necessary. As such, the extraction sector has the potential to offer growth opportunities to less economically developed countries so long as better management is implemented (UN Press 2019). The idea that mineral resource wealth should reduce poverty and induce growth in countries has widely spread and grown, but this phenomenon infrequently occurs for many reasons (Aubynn 2009). Fluctuations in global commodity prices of mined materials make low concentration reserves economically viable for extraction only when prices are high, and high concentration reserves viable only when prices are low. These large swings in production can result in inconsistent return on operation, creating significant lag times between supply and demand (Aubynn 2009). The political uncertainty around a low-carbon society creates additional uncertainty around investments that could stabilize production, and poses a discouraging risk to investors, further slowing development (Ali et al. 2017, de Koning et al. 2018). These fluctuations and uncertainties support that economic feasibility of extraction will be the main bottleneck in meeting metal supply.

Even so, Odell et al. (2018) argue that current research and development has focused on maintaining the extractive industry in the face of climate change, where in fact, it should focus on climate change as the driver for improving and updating extraction methods. Thus, modifications to technology and methodology will address new climatic and environmental constraints, rather than continue with inefficient and environmentally risky practices. For example, climate change could reduce water availability for processing ore and the frequency of severe storm events may increase damages to mining infrastructure. To guide development that will create tools for long term use, as well as to reflect environmental and social concerns in public policy, Odell et al. (2018) created a framework to understand the dynamic relationship between climate, mining and social policies (Figure 5.8). For example, the relationship between climate change and mining activity may present as reduced water availability to process and refine ore (1 in Figure 5.8); refining in mining operations can use up to 5% of global energy, releasing greenhouse gases and contributing to climate change (2 in Figure 5.8); public policy and industry practices will interact to create regulations for mining and responding to climate change, influencing both (3 in Figure 5.8); mining activities (such as the creation of acid mine drainage) and climate change (creating reduced overall water availability) will converge on certain factors like the accessibility of clean water (4 in Figure 5.8); how the public perceives risks and consequences that result from climate change and/or mining will feedback into public policy and socially appropriate industry practices and regulations (5 in Figure 5.8); this framework can be applied across the world, operating in different political and economic contexts (6 in Figure 5.8).

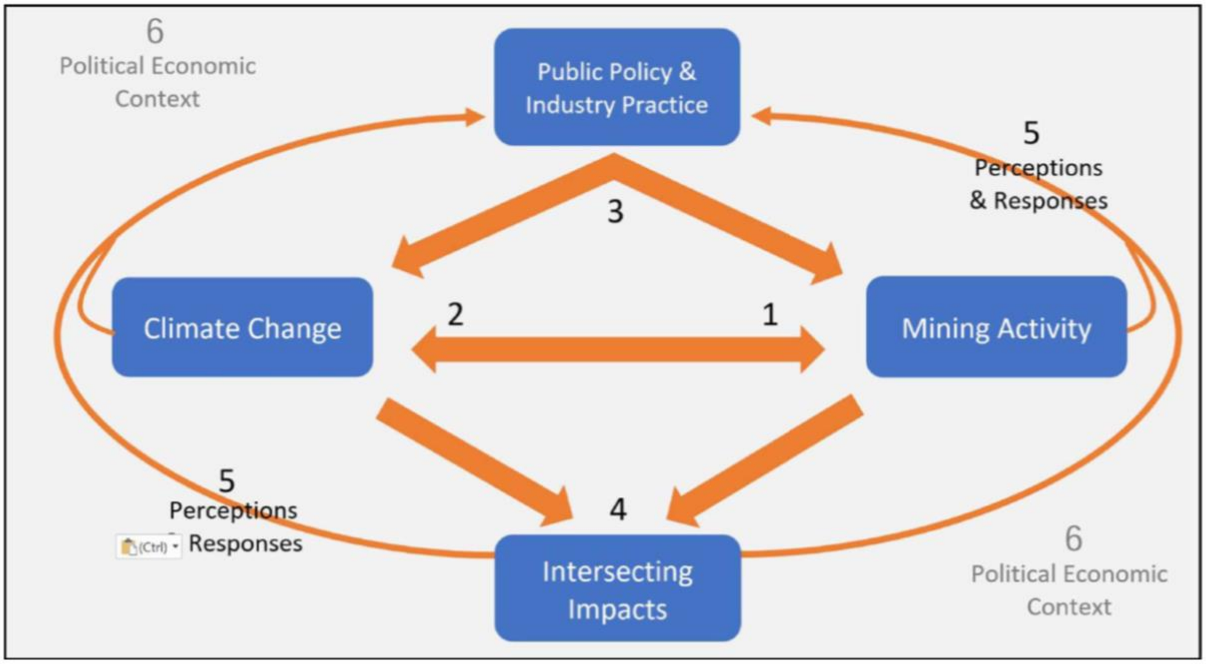


Figure 5.8 A framework to use in developing new technologies and policies within the extraction sector, emphasizing climate change as a driver of adaptation. (Odell et al. 2018)

In addition to updating tools and extraction methods, research should focus on creating tools that are cost-effective and accessible to economically less-developed countries that seek to exploit their mineral wealth in pursuit of growth. This can be especially important in countries like Ghana, which supplies major quantities of gold and diamonds to the United States. The presence of both large-scale mining operations and artisanal small-scale mining (ASM) operations creates tension and conflict between local communities and mining corporations. While ASM operations contribute significantly to the global metal supply, the downside is that individuals work in hazardous occupational health conditions using inefficient and rudimentary tools that results in poor human health and negative environmental impacts. The formalization of ASM by governments has yet to effectively address and manage these concerns, and issues over land ownership and traditional rights of local communities to resources leads to violent conflicts (Aubynn 2009). Such cases arise around the globe and exemplify a central issue embedded in resource extraction that has yet to be tackled: primarily, that negative health and environmental impacts disproportionately target the poor to meet demands placed by richer, more developed countries.

To promote ethical practices in mineral supply that protect the environment, people of all nations and the local communities, the United Nations Environmental Assembly offers six specific actions that outline ethical practices in the industry: 1) reach consensus on international targets for global mineral production, 2) monitor impacts of mineral production and consumption 3) improve coordination of mineral exploration, 4) harmonize global best practices for responsible mineral resource development, and 6) develop maps and inventories showing the availability of recyclable metals (Ali et al. 2017). These six actions importantly highlight areas in the career of environmental scientists where ethics should be practiced and stressed. However, the implementation of these actions requires global cooperation among scientists, a task difficult to carry out while respecting the ethics and beliefs of a diverse global community.

For environmental scientists, the relationship between ethics and science may seem less than obvious; science operates in "facts" and functions within clear laws of nature, while ethics are social constructs that vary culturally. This view thus creates different guidelines for acceptable practice based on where science is being conducted. However, this simple dichotomy is a common misconception, as science can only offer a best solution to a problem or the most direct path to achieve a goal; science cannot assert whether it is right or wrong to pursue these paths (Briggle and Mitcham 2012). Because of this limitation, science and ethics are entangled.

As scientists, we aim for objectivity by removing bias by using blind experiments, incorporating random sampling, and considering all information, whether or not it supports our claim. Through objectivity, scientists support the principle that the derivation of arriving at an answer is most important, rather than arriving at the right answer. This principle should incorporate ethics into practices but requires policing and enforcement through the peer review process that works in theory, but not perfectly in practice. Still, there will always be inherent bias that cannot be removed from science, as the most qualified individual to examine a scientific question has selected that field of study through personal interest and preference. This calls for a closer look at how science and ethics operate together.

6. Food Production

6a. Introduction

Jacob Zimmerer

Food brings us directly to the interface between humans and the rest of the natural world. What we eat largely determines our influence on the land. Our quest to provide enough food for a growing population has driven us to, at times, prioritize productivity over ethics, quality, connection, and the health of ecological systems. There is an ethical obligation to ensure that humanity is adequately fed, yet the likelihood of current practices being able to achieve this in the face of dwindling resources, without other devastating costs, seems unlikely at best. While our understanding of how to practice agriculture more sustainably is growing, it seems that the implementation of these practices may come at the price of producing less food, at least at first. Nonetheless, if we are to successfully feed humanity and maintain ecological systems both in the short- and long-term, we are going to need to be open-minded and creative. This means investigating and applying a diverse set of potential solutions, from a variety of sources.

In many parts of the world, fertile, living ground has been stripped of its vigor through years of intensive, poorly managed agriculture (Horrigan et al. 2002). Monocultures dominate vast landscapes, taking away the land's innate ability to provide ecosystem services to humans such as carbon sequestration, pollination, clean water, traditional medicines, wild foods, and raw materials (Foley et al. 2005). The associated loss of wildlife habitat has left limited opportunities for our non-human kin to persist (Kolbert 2015). Our current food system fails to integrate within natural systems, instead opting to control and dominate in hopes of maximizing productivity. Yet it is clear, disregarding all the aforementioned losses, that the levels of productivity we have achieved cannot be sustained into the long-term with increasing scarcity of land, nutrients, water, and a changing climate. Questions of food production into the future are laced with ethics. Solutions do not exist in a bubble separated from the context of a diverse world, filled with humans who hold different values and visions for the future. Yet, most of us can agree that ensuring people do not starve is essential. So how do we go forward?

It is not impossible in the modern world to grow up without ever having picked a vegetable or killed an animal (directly). In the words of Aldo Leopold, the famed ecologist and conservationist, "There are two spiritual dangers in not owning a farm. One is the danger of supposing that breakfast comes from the grocery, and the other that heat comes from the furnace." Creating a sustainable food system requires a population that is engaged and willing to buy-in. The behavior of individuals regarding their food is central to this task. The lack of connection between people and their food may be one of the first barriers to creating a viable food system moving forward. Consumers have the power to choose goods that are produced in ecologically-friendly ways. Yet, the general lack of awareness or apathy surrounding the issues of food production leads to stagnation. The creation of environmental policy that pressures shifts in food systems rely heavily on an informed and passionate population. An example of this is the uproar surrounding DDT in the 1960's, which led to a variety of environmental reforms including the banning of the chemical for agricultural use. The associated consequences of using this chemical on human and ecological health outweighed the potential benefits for agricultural production. This represents a critical moment in the history of agriculture where the ethical obligation to feed the world in the short-term did not outweigh the ethical obligation to protect the environment and secure the land's ability to provide food in the long-term.

People have been creatively procuring food for thousands of years. From hunting and gathering to agriculture, there are a variety of ways that the land can provide sustenance. While human population on the North American continent was substantially lower pre-1492, indigenous people were successful in maintaining human populations and the resources that they needed to do so. The suite of information about ecosystems gathered by indigenous people over generations is termed traditional ecological knowledge. This knowledge ties food production to the ecosystems in which they take place. There is substantial evidence that Native Americans actively tended the land in order to sustain and increase production of a variety of foods. On the Pacific Coast, tribes engaged in salmon husbandry, adjusting harvest to ensure sustained salmon runs in future years (Johnsen 2009). Tribes across the continent used fire to promote increased berry yields in species of *Vaccinium* and provide better habitat for ungulates that could be hunted for food (Kimmerer and Lake 2001). There are countless examples of ways that Native Americans used their generational knowledge to creatively maintain sustainable food systems that provide adequate amounts of food while still bolstering ecological health. Traditional ecological knowledge represents a significantly underutilized source of inspiration for how to create a more sustainable modern food system.

The scientific community has not shied away from the task of researching and developing solutions that can feed the world and address ecological issues. There are already a variety of practices that can address some of the issues associated with our current agricultural practices, yet these solutions are not always adopted by individuals or included in policy. In some cases, these practices may decrease production, which for smaller-scale operations may be the difference between profit and losses. In the larger-picture, decreasing production does not match well with a growing human population. In this paper, we will provide insights into the ethical implications and viability of a few practices that are being developed and applied in food production in order to increase the ecological value and sustainability of food systems.

6b. Integrated Pest Management

Luke Reents

One way to move towards sustainable food sourcing can be seen through the implementation of integrated pest management (IPM) in agricultural scenarios. Currently the majority of pest management tactics within agriculture are dominated by conventional practices. While conventional pest management practices within conventional systems bring benefits, inevitable drawbacks are observed. Conventional practices aim to simply eliminate pest populations to increase crop yields with a main focus on maximizing immediate results, failing to account for larger and less evident issues. These issues include pollution of water, increase of future pest outbreaks, pesticide resistance, elimination of non-target organisms, and more. Long term failure to address these issues will not work with increasing food demand and ethical issues revolving around environmental impacts. Integrating IPM into agricultural practices seeks to address these issues while still providing a similar product to that of conventional practices. This section of the paper provides an overview in regards to IPM as a means to address food sustainability. Fundamentals regarding IPM basics, common IPM practices, IPM as a means for addressing issues, and IPM drawbacks will be discussed.

IPM is a practice involving coordinated use of multiple predetermined tactics for controlling pests while adhering to ecological and economic impacts (Ehler 2006). IPM practices done well accounts for multiple activities: simultaneous management of more than one pest; regular monitoring of pests and of natural pest enemies; considering economic or treatment thresholds when applying pesticide; and the integrated use of multiple suppressive tactics (Ehler 2006). The term “integration” within IPM is the incorporation of natural enemy and other antagonist levels as well as the use of tactics that preserve those agents through compatible and non-disruptive practices. When combining the responsibilities multiple pests can be removed, bringing pesticide use to a conservative level.

Currently IPM practices can be narrowed into four categories to be used in conjunction with one another: cultural, mechanical, biological, and chemical. Of the practices that exist, biocontrol through biological practices have been proven to be common and effective. The main function brought through biocontrol within IPM is to promote pest suppression through attracting or releasing enemies of pests and/or removing unnecessary vegetation that may benefit pests. Alterations in vegetation can offer pest suppression through 'top-down' and 'bottom-up' enhancements. 'Top-down' enhancements offer management through the amplification of natural enemies that do not harm the crop. 'Top-down' enhancements include intentional non-crop vegetation within monocultures through the promotion of weed growth, diversification within the monoculture, diversification of vegetation bordering the monoculture, monoculture abandonment, diversification of vegetation beyond the field margin, farm-wide diversification, and landscape level changes (Gurr et al. 2001). Increases in biodiversity within each 'top-down' tactic promote populations of different pest enemies. 'Bottom-up' enhancement includes removal of weed species through herbicides and other practices that suppress pest food and shelter sources. Of the categories described, biocontrol is an example for just one possible approach that is integrated with practices from the other management categories.

As previously discussed, issues such as climate change, food security, water pollution, and economic factors have major relations with agricultural practices. IPM may not be the sole solution, but it may be an effective step forward in reducing and coping with them as future intensification of these issues is inevitable. Food security is an increasing problem observed through intensifications in climatic disruptions such as droughts and floods, which in turn affect biota in natural and managed levels. In addition to biotic stress, populations and food demand are increasing, putting pressure on agricultural systems. Currently global cropland has less than half of the availability that it once had and more than 900 million people are now classified as hungry or malnourished (Birch et al. 2011). Breaches in food security can be seen through crop losses via pests. On a global level, pests consume food that could feed roughly one billion people (Birch et al. 2011). With increasing climate variations, seasonal and long term changes may affect biota and population dynamics of pests as well (Karuppaiah and Sujayanad 2012). Excessive pesticide use leads to resistance within some pests, proving to be an unsustainable process that must be addressed. With the integration of IPM tactics, pesticide usage can be brought to a minimum, promoting a sustainable approach to this issue. Excluding climate change and pests, pollution from agriculture is a large contributor to water quality issues through non-point source pollution. Currently, non-point source pollution is one of the main causes of water pollution globally (Xu 2014). Agriculture contributes to this form of water pollution primarily through leaching and runoff events, which moves excess loads of manure, fertilizers, and pesticides that have accumulated on landscapes, thus promoting water quality issues. IPM practices can integrate multi-species perennial systems, cover crops, and minimal pesticide use, and significantly decrease runoff (Jarchow et al. 2012). Outside of environmental implications, IPM practices can be much more cost effective for the farmer rather than conventional practices, where pesticide use is continuous.

While IPM has been shown to be a very effective step towards a sustainable future, it is not a perfect system. Little evidence has been shown that IPM has been implemented to any significant extent in American agriculture and the failure has been shown to trace back to certain constraints (Ehler 2006). When comparing IPM practices to conventional, the level of involvement for IPM is much more intense. The serious involvement within IPM primarily roots from the significant research and ecological understanding needed to choose and maximize effective practices, as different pests have different control methods. After practices are implemented, consistent field monitoring is required as well. Finally, in the long run, IPM is economically sustainable, but start up costs are typically high. IPM can be time and energy intensive and may be overwhelming to practitioners, highlighting the ease of conventional practices.

Impacts due to climate, anthropogenic activities, and population demographics are projected to worsen, which will result in food insecurity. Where these impacts are becoming more evident, it is becoming clear that agricultural practices have significant influences. With the increase in urgency to implement more sustainable mechanisms regarding food sourcing and environmental consciousness, IPM comes to light. IPM can be seen to be extremely broad with a narrow focus on sustainable efficiency and environmental diligence. IPM addresses contributions to issues revolving around climate change, food security, pollution, and economics. While research for more effective tactics will benefit IPM, research into ways to create a more user-friendly system may be necessary to gain large scale implementation. Research into the simplification and cost reduction of practices along with the creation of a fixed definition for exactly what IPM entails will be beneficial. Demonstrating the effectiveness of IPM can be achieved through on farm research as well (Birch et al. 2011). Though IPM practices are seen much less than that of conventional, IPM research is expected to continue, as conventional "quick fix" applications are proving to be unsustainable.

6c. Crop pollination services provided by native pollinators

Joshua Botti-Anderson

Pollinators play an essential role in the maintenance of nearly every terrestrial ecosystem, where their facilitation of plant reproduction enables the continuation of many important ecological processes. Among angiosperms, 85% are dependent on mutualistic interactions with animals for pollination (Ollerton et al. 2011); of the crops grown for food, more than 30% rely on pollinators (McGregor 1976). While pollinators provide pollination services to both agricultural and natural ecosystems, it is important to acknowledge the distinction between wild and managed species. Managed species, which include the European honey bee (*Apis melifera*) and alfalfa leaf-cutting bee (*Megachile rotundata*), are often deployed to fill pollination needs in monoculture systems. Stemming from their amenability to management and rearing as livestock, the advantages of using such species include the ability to achieve high localized abundances with timed release during peak bloom, as well as their disposition to nest in high densities in artificial structures. Furthermore, the lack of natural habitat characteristic of many agricultural landscapes limits the magnitude of pollination services provided by wild pollinators, which often creates the need to utilize managed bees to compensate for this deficit (Kremen et al. 2002). Nevertheless, a heavy reliance on mass-reared pollinators can create production instability; managed pollinators are highly susceptible to dramatic increases in mortality. Honey bees, which are the most commonly utilized species, experience a phenomenon known as 'colony collapse disorder.' The potential culprits of this include disease, pesticide residue, and genetic homogenization of the colonies (Ellis et al. 2010). These insecurities associated with managed pollinators exemplify the need to shift towards reliance on wild pollinators for crop pollination services.

Despite the widespread use of managed species, diverse communities of native pollinators within and adjacent to crop fields possess the capacity to provide significant pollination services to agriculture. A study of field sites spanning the globe found that honey bees were less effective pollinators of flowering crops than wild pollinators, whose visitations had a stronger effect on seed set, a metric of production and pollination efficacy (Garibaldi et al. 2013). This result was replicated in a more regional study, where native bees, including some specialist species, played a larger role in the pollination of confection sunflowers than managed honey bees (Mallinger et al. 2019). Clearly, the production of food is highly dependent on ecosystem services provided by wild pollinators, but the reliability of such services is linked to the quality and areal extent of natural habitat in the agricultural landscape. In addition, total pollinator abundance is resistant to annual fluctuations only if adequate species diversity is present in the community (Kremen et al. 2002). This source of stability can be explained by the structure and strength of interactions between pollinators and their floral hosts, which organize to form complex plant-pollinator networks. A study using simulations found that removal of generalist pollinators, which form a high number of connections in pollinator networks, resulted in a loss of their floral hosts and had a cascading negative effect on the community (Memmott et al. 2004). As such, there is an important difference in population susceptibility between managed and wild pollinators: while the health and abundance of wild species is linked to habitat quality and community composition, the instability associated with managed species stems from their artificially high nesting densities and mass production of a single species (Ellis et al. 2010). Therefore, approaches aiming to increase pollination services from wild pollinators must take into consideration both habitat quality and species conservation. In addition to extending their services to the production of certain crops, wild pollinators play an essential role in the maintenance of natural ecosystems which, in addition to pollination, produce many ecosystem services, including maintenance of local environmental stability and biological pest control. Thus, efforts to bolster resident pollinator populations through habitat augmentation serves two functions: conservation of native species biodiversity and production of ecosystem services.

The divergent effects of habitat conservation and agricultural expansion may seem ironic when considering the crop production benefits of wild pollinators, because the conversion of natural habitat to simplified agricultural landscapes is associated with many deleterious effects on the composition and health of native pollinator communities. Among the most direct consequences of agriculture include diminished areal extent and increased isolation of natural habitat, which have been found to decrease the abundance and diversity of wild bees (Steffan-

Dewenter and Tscharntke 1999, Kremen et al. 2002, Steffan-Dewenter et al. 2002). As the replacement of natural habitat, agricultural landscapes often lack the nesting resources and have an altered phenological synchronicity of floral resources with normal pollinator foraging activity. In fact, a study evaluating the phenology of pollinators in agricultural, urban, and natural environments found that pollinator foraging activities in agricultural areas aligned with peak crop bloom, and their activities differed from those in natural communities (Leong et al. 2015). Because these phenological changes in agricultural landscapes are associated with deteriorated community composition (Steffan-Dewenter et al. 2002), the remaining species that are tolerant of such landscapes and food availability regimes likely form less diverse communities with a lower ability to pollinate crops (Kremen et al. 2002). A study that compared historical plant-pollinator communities to those in the same area following a century of landscape conversion found that fewer species were present in the community, and that the remaining interactions were significantly weakened (Burkle et al. 2013). Clearly, landscape conversion adversely affects wild pollinator communities and, subsequently, their ability to provide pollination services to crops. The components of community composition and habitat quality should be a central focus of strategies aiming to maximize the pollination services provided by native pollinator species in agricultural landscapes.

The dependence of native pollinators on floral interaction partners and nesting sites creates the need for restoration initiatives to provide sufficient coverage of natural habitat containing both structural components and diverse arrays of native plant species. Wildflower plantings that provide floral resources throughout the growing season have been found to sustain more diverse and abundant assemblages of pollinators than unaltered weedy patches (Williams et al. 2015). Additionally, the costs associated with establishing wildflower strips (e.g., seed mixes, equipment) can be compensated by higher crop yields via increased pollination (Blaauw and Isaacs 2014). Such benefits of habitat restoration may play a role in guiding incentives for farmers to conserve native pollinator species in intensive agricultural landscapes. Another way to increase numbers of native pollinators is to plant hedgerows, which consist of shrubs planted along field edges. Hedgerows can act as a nursery for native flowering plants and provide nesting sites for pollinator species that nest in aboveground cavities. Like wildflower plantings, hedgerows bolster community composition, enhance the availability of floral resources, and promote pollinator dispersal into the crop field (Morandin and Kremen 2013).

6d. Implementation of Adaptive Agriculture Practices

Abigail Northrup

Agricultural food production is one of the largest uses of the world's land, accounting for 26.8% of the total 149 million km^2 of land (Ritchie 2019). Like many human activities, agricultural food production has changed the global nutrient cycles over time, primarily the carbon, nitrogen, and phosphorus cycles. The imbalances of these cycles have caused ecological problems in terrestrial and aquatic systems. Focusing on the carbon cycle, agriculture has been at the forefront of attention for CO_2 production, contributing 9.6% of the total 6,457 million metric tons of carbon-dioxide equivalent, resulting in concerns about agriculture's effects on global change, specifically climate change (Climate Change … 2017). Designing alternative methods to conventional agriculture that both reduce CO_2 emissions and increase C sequestration has become a focus of research, especially as climate change and human population growth produce further uncertainties for the world's food security and global markets.

Adaptive agriculture practices provide methods of producing food, through farming and raising livestock, that are more sustainable and ecologically responsible (Dubey 2019). These practices have many names but their common goal is to encourage sustainable yet productive techniques, including: increasing efficiency of water and nutrient use, minimizing soil disturbance to decrease soil erosion rates, increasing crop diversification, and altering crop densities. Adaptive agriculture practices can be applied at different scales from landscape to the fields and more specifically to the species of crop. This spatial structure is useful to create building blocks that contribute to larger schemes of an ecologically balanced and possibly beneficial landscape system. Agroecology revolves around the themes listed to portray cropping systems as plant communities, to create a self-sustaining and productive system. Each producer's scenario is unique in agroecology with no "one-size-fits-all"; cropping systems are recognized for their complexities and management strategies are developed with the goals of the producer in mind (Hatt 2016). Leaving stubble and litter on the landscape following harvest, planting hedgerows, and implementing no-till or reduced till systems are among the alternatives that have successfully been applied across the United States. The improvements seen with these sustainable practices is evident, but implementing such practices for producers on large-scale and small-scale operations can result in a period of low profit and productivity.

As pressures grow to implement these sustainable practices in order to combat nutrient loading scenarios and our growing CO_2 production, it is important to ask how producers can be supported in practicing such methods. The implementation of agroecology and sustainable agriculture themes mentioned earlier is risky for producers; creating a period of loss in profit and production. Programs to help producers with this transition period must provide both for the producer's goals and the environment's welfare. The United States Department of Agriculture's (USDA) Natural Resource Conservation Service (NRCS) works with producers on cost-share programs in order to encourage adoption of a new practice that may enhance efficiency and productivity while promoting ecosystem health. Some of the programs include the Conservation Reserve Program (CRP), aimed at reducing soil erosion and protecting ecologically sensitive areas through the retirement of unproductive cropping lands; Wetland Reserve Program to retain and restore wetlands; and Environmental Quality Incentive Programs (EQIP) to improve water quality issues from point and nonpoint sources (Parry 1998, Plantinga 1996). The conservation title of the Farm Bill in 2018 made up 7%, or $30 billion, of the funding (What is the Farm Bill … 2019). The conservation funds were allocated towards increasing the enrollment limit of CRP lands and expanding EQIP as well as reauthorizing research to continue the projects and programs in the extension and research settings. These programs are not the perfect answer to the implementation of sustainable practices, but they can be of great use to producers as they consider practicing agriculture that focuses on long-term food security with a healthier ecological effect.

In 2018 in Montana, 5.7 million acres have been improved through various practices that were implemented through the NRCS (NRCS Montana … 2018). One of these practices is cropping rotations; in 2013, there were just over 600,000 acres of pulse crops in Montana. Four years later that increased to over 1.5 million acres (Growth of Montana … 2017). The idea behind crop rotation is to create a rotation that is unique to the area's climate conditions and provides diversity by varying cropping practices from year to year, nutrients can be added back into the soil also will the use of a legume. Cover cropping has been incorporated into some crop rotations as an alternative to a fallow crop rotation in order to improve soil health by increasing plant diversity as well as protecting soils from erosion and the benefits from keeping a live root in the soil. Cover cropping can also be useful to break up compacted layers or add nutrients to the soil with legumes, ideally reducing the amounts of fertilizers used (Dubey 2019). Crop rotations and cover cropping are also used individually and in combination as a part of integrated pest management, that was mentioned earlier. By adding different crops at different times of the year, pests like the wheat stem sawfly cannot repeat their life cycle every year because of the cropping differences, reducing the risk of insecticide-resistant pests (Roberts 1988). Farmers are able to visit their local NRCS office to find information on successful crop rotations for their area. Cropping systems with and without cover cropping systems have been studied at agriculture research centers to look at the change in yield of a specific crop like winter wheat and soil nutrient levels such as nitrogen rates (Cover Crop … n.d.). If the crop rotation system is integrating a new cash crop it is important to ensure there is a market and to communicate with the local USDA office for insurance policies on the cropping systems. Despite the challenges producers face in the implementation of a new technique, some successes have been found in yield improvements and ecological conditions through the replacement of summer fallow with a diversified cropping system, even in dryland systems (Lenssen et al. 2007).

Cropping rotations in Montana may be a great tool as we consider growing uncertainty in the future of agriculture with projections of drier conditions and rising obstacles of herbicide and pesticide resistance as feeding continuous human growth. However, the challenges and limitations of sustainable agriculture techniques emphasizes the urgent need for thorough research to successfully apply these sustainable principles in varying conditions to increase crop production and soil health. In order to increase the participation of sustainable practices, it has been proposed producers work with researchers, possibly conducting their own research or giving their input to structure an experiment (Anderson 1990). The farmer's valuable input makes agricultural research much more applicable but there is a balance in solving the problem for the short-term benefit of the producer versus contributing to the broader field of knowledge to address larger issues in the future (Anderson 1990). Although every producer has a different way of doing things, we find common ground in that the land provides what we need and it is in our best interest to keep the system healthy and invest in its future. As researchers and producers look to the challenges ahead, it is import to work collaboratively to support a sustainable future for agriculture in which ecological systems are improved for our benefit and the organisms we share the land with.

Conclusion

This paper provides a broad overview of a small subset of potential pathways towards a more sustainable food system. Each approach has its merits and drawbacks that should be considered in further research, development, and application. Integrated Pest Management is still in its early-stages of development and has not been widely applied. Finding ways to offset the costs of additional labor, learn new techniques, and create an overall user friendly system may be a good first step to encouraging a larger-scale shift away from conventional pest management. Currently, Integrated Pest Management is starting to be encouraged through education and assistant services given with a combination of programs and consulting groups. One example of these services can be seen with the Environmental Incentives Program (EQIP) from the NRCS, which offers financial assistance for the payment of activities associated with practices in Integrated Pest Management. Groups like Regional IPM Centers promote Integrated Pest Management through online educational services as well. While further research into pest management practices is beneficial, education, outreach, and assistance through the use of programs and groups will be effective tactics for further Integrated Pest Management implementation.

Increasing the ecosystem services provided by native pollinator communities will require targeted efforts to ensure that quality habitat is available to support these communities in agricultural landscapes. Federal incentives, such as the Pollinator Research Action Plan of 2014, broadly support research into both managed and unmanaged pollinator species. However, an applied approach at the scale of individual farms is necessary to produce the changes needed to support these communities across privately-owned agricultural lands. Such incentives might include subsidized seed mixes and equipment to offset the cost of established wildflower strips or hedgerows, in addition to any arable land sacrificed for habitat restoration. Scientists must work to integrate basic principles of community and landscape ecology into applied scenarios on flowering crop farms. Additionally, more research should be conducted to evaluate individual species' resiliency in modified landscapes, as well as their efficacy of crop pollination. While there is increasing interest in creating programs that establish payment for ecosystem services, more emphasis needs to be placed on federal programs that could bolster native pollinators. This could look like an incentive program where landowners are compensated for creating pollinator habitat that increases levels of associated ecosystem services.

At this stage in the process of addressing the sustainability of our current food system, in regards to both food production and ecological health, all solutions should be given serious consideration. The path forward is likely to be wrought with ethical questions that we will have to address as a society. These conversations require active participation from a diverse group of people with a wide-range of backgrounds. As scientists, we must ask ourselves two primary ethical questions surrounding food production: To what degree should we step outside of our defined roles as scientists and move into the realm of advocacy and what directions will we choose to focus our future research? Our individual voices, values, and ethics, as well as our collective research, will be invaluable moving forward in addressing the issues outlined in this paper.

7. Glyphosates

Elizabeth Hecker and Graham Mills

History of Glyphosate

Weed species have been an issue in cropping systems for thousands of years. The presence of unwanted species has posed harmful effects on crop production, with the greatest effect being reduced crop yields. Weeds reduce the productivity of crops due to their ability to establish quickly and their ability to compete for water, sunlight, and nutrients. As expected crop yields are reduced, profits are equally affected, creating financial unrest amongst farmers. This financial drive highlights the desire for a reduction in weed species within agricultural settings. Before the 19th century, the management of weeds was primarily confined to tillage for seedbed preparation. However, during the late 1800's and extending throughout the 1940's, research regarding the use of inorganic compounds for weed control grew in popularity amongst farmers (Timmons 2005). The Green Revolution[1] brought forth an acceptance of mass herbicide use within the agricultural industry and the continuous discovery of new herbicides such as 2,4-D and glyphosate.

Glyphosate was patented as the active ingredient for the herbicide Roundup in 1974 by the agrochemical and agricultural biotechnology corporation Monsanto (USDA 2017). Since then, over 1.6 billion kilograms of glyphosate have been applied within the United States (Bedbrook 2016); making it one of the most widely used herbicides throughout the U.S. The popularity of this herbicide stems from its use on transgenic, glyphosate resistant crops (GRCs); which were introduced within the late 1990's (USDA 2017). The combination of herbicide and herbicide resistant crops have brought forth one of the most effective and inexpensive weed management strategies in modern agricultural practices. The ease of glyphosate use explains why in 2014, farmers applied ~1.0 kg of glyphosate on every hectare of United States cultivated cropland (Benbrook 2016). This mass application of herbicide within the past decades has raised concerns regarding glyphosate translocation, herbicide resistance to glyphosate, and its health

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[1] The Green Revolution refers to a series of research, development, and technology transfer initiatives occurring between the 1940's and the late 1970's that increased agricultural production around the world (Tapu, 2013).

impacts on humans and other organisms. The purpose of this paper will be to explore the mechanisms of glyphosate and the ethical implications of glyphosate usage in crop systems.

Glyphosate Composition & Function within Plants

Glyphosate is a broad-spectrum systemic herbicide composed of phosphonic acid that results from the oxidative coupling of methylphosphonic acid and glycine. It is the only herbicide that actively targets broadleaf weeds and grasses through inhibiting the synthesis of 5-enolpyruvyl-3-shikimate enzyme (EPSP; USDA 2017). Glyphosate enters the plant by absorption through the foliage and is translocated into the phloem where it targets the EPSP enzyme. EPSP is a key enzyme within the shikimic pathway which is involved in the synthesis of aromatic amino acids. By inhibiting EPSP, a depletion occurs within the aromatic amino acids—tryptophan, phenylalanine, and tyrosine—which are critical for protein synthesis in plants. Destroying the pathway in which proteins are assembled results in halted plant growth and development, causing morphological damage through distortion in leaf shape, interveinal chlorosis, stunting, crinkling, and cupping of developing leaves which eventually leads to necrosis of the plant within three to seven days (EPSP Synthase Inhibitors… n.d.). The development of glyphosate-resistant crops has allowed glyphosate application within agricultural systems with no crop injury. These crops have an alternative EPSP enzyme, which remains unaffected by the glyphosate inhibitor. However, the application of glyphosate on crops that are resistant causes concern for bordering crops and vegetation communities that lack resistance due to the translocation of glyphosate throughout surrounding areas.

Glyphosate Translocation

Wind

The majority of herbicide application within agricultural settings occurs through the use of a boom sprayer. This method is used due to its ability to cover large areas of land, but it does not guarantee that all of the herbicide will be applied directly over the desired crops. Weather conditions like high wind speeds may transport glyphosate particles downwind from the targeted area and settle elsewhere; this phenomenon is referred to as spray drift[2]. In cropland systems,

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[2] It should be noted that herbicide labels include a maximum wind speed that is appropriate for the application of said herbicide. According to the herbicide label for glyphosate the maximum wind speed recommended for application is 2 mph. It is clearly stated that avoiding drift spray is the responsibility of the applicator.

spray drift of glyphosate may result in crop damage and yield loss within neighboring fields, along with negatively affecting non-target plant communities that lie outside of field edges. Accidental application through spray drift of glyphosate within these communities may reduce rates of biodiversity, reproduction, and composition (Cederlund 2017). Farmers can reduce the likelihood of spray drift by taking necessary precautions such as spraying when the weather conditions are compliant to the herbicide label, utilizing specialized spray boom nozzles, using shielded boom sprayers, and/or sanctioning buffer zones between fields (Reducing Pesticide Drift…2016). These precautions do not guarantee that spray drift will not occur. Although it is possible to quantify the amount of spray drift that may transpire within immediate areas around the target field, it is still unknown how long glyphosate particles remain suspended within the air column. This lack of information on glyphosate suspension when introduced into the air highlights the need for further research on glyphosate interactions within the atmosphere.

Soil

Once glyphosate is applied to a desired crop, only a portion of the herbicide is used to actively eliminate weed species. A greater portion of the chemical is introduced into the soil without making contact with weed foliar cover. According to the EPA Glyphosate Product Label, glyphosate persistence within soil is nearly negligible due to its rapid rate of degradation within this medium. Glyphosate is known to adsorb strongly to soil particles, thus limiting its vertical movement below the initial 6- inch soil layer (EPA 1998). Glyphosate degradation in soil is a predominantly microbial process, so the vertical distribution of glyphosate in soil is incredibly important. Biological degradation of glyphosate occurs when microorganisms release oxidase, an enzyme that promotes the breakdown of the carbon and nitrogen bonds present within glyphosate. Once these bonds have been broken, aminomethylphosphonic acid (AMPA) and glyoxylic acid are produced. These acids are then used by soil microorganisms as a carbon source to complete their metabolic requirements (la Cecilia et al. 2018). Although the degradation within soil occurs at a rapid pace, this relies heavily on the microbial community that is present within the rhizosphere. If the microbial community within the treated crop field is not highly active due to poor soil conditions, there is a greater risk that glyphosate may persist within the soil. This can be an issue when glyphosate residues are introduced to water through precipitation events or irrigation. Glyphosate present in water will not readily degrade. This highlights the possibility of glyphosate being transported by surface water movement and/or being leached further down into the soil profile, eventually into groundwater. Another area of concern regarding glyphosate residues in soil is the occurrence of erosion. Because of its strong sorption potential, physical movement of topsoil by wind and water can result in the unintentional movement of glyphosate (Silva et al. 2018). Non-target plant species and water supplies can face degradation and/or contamination when the presence of glyphosate has spread to regions that were not selected for herbicide application.

Water

Glyphosate does not actively degrade within water due to the lack of microorganisms that are able to use glyphosate to meet their metabolic needs. It remains within solution until a reintroduction into soil occurs. This allows for the herbicide to be washed away by rainwater into irrigation ditches which can then be transported into stream and river corridors (Borggaard 2007). In 2014, a study conducted under supervision of the United States Geological Survey (USGS) collected water samples from 550 sites throughout the Midwest to test for the presence of glyphosate residue and its degraded product AMPA. 59% of 470 sites contained either fractions of glyphosate and/or AMPA within water samples from ditches, drains, rivers, and streams (Battaglin et al. 2014), illustrating that glyphosate can be commonly found within agriculture-adjacent waterways where glyphosate application is a common practice. The presence of this herbicide within these bodies of water raises concern regarding the health impacts on aquatic microorganisms. Microorganisms are vital to freshwater ecosystems because they form the basis of the food chain within these environments by actively breaking down organic matter. Experiments conducted in laboratory settings show that the growth and biodiversity of aquatic microbial populations were disrupted when in the presence of glyphosate at levels commonly found in agricultural run-off (Pérez et al. 2007). A reduction within aquatic microorganism populations can create disturbances within the ecological function of river ecosystems; creating regions of ecological degradation and failure throughout once healthy river systems. If the usage of glyphosate continues to increase throughout the 20th century, there may be greater negative impacts towards the health of aquatic organisms and ecosystems; which raises the possibility for a depletion within non-contaminated drinking water in areas of the United States where glyphosate is heavily used.

Glyphosate Usage

Crop Application

The application of glyphosate should be completed by following the herbicide label provided with the chemical. The instructions listed on the label are vital and should be followed precisely to ensure safe and proper implementation, reducing environmental and human health risks while increasing application accuracy. The product label includes instructions regarding how to properly mix glyphosate for each specific application, how to use different application techniques, and application methods for different crops. The commonly used application equipment and techniques for glyphosate include aerial application, ground broadcast equipment, and small-scale equipment. The following will address the advantages and disadvantages of utilizing these application equipment and techniques.

Aerial application refers to the utilization of specialized aircraft such as helicopters and/or planes that have been modified to hold and dispense liquid herbicides. This method of application is often the only economically efficient method for applying herbicides. The cost of using aerial application ranges from $10 to $15 per acre[3], making it one of the most inexpensive methods of herbicide application (NFS 2012). It permits for large and remote areas to be treated rapidly, especially compared to other application methods. Aerial implementation of herbicide has been proven to provide higher crop yields due to its non-disruptive technique of treating the area from above and not within, reducing the probability of crop damage by equipment (NAAA n.d.). However, the greatest disadvantage of using this application technique is the application accuracy, which is controversial given the high probability of spray drift. The glyphosate product label states, “Application must be avoided below 2 mph due to the variable wind direction and high inversion potential”. It is important to note that the topography of the region where application occurs may alter wind patterns (Glyphosate Product Label 2016). If these circumstances, along with equipment specifications and particular weather conditions are not adequately met when glyphosate application occurs, herbicide that should have been applied to

[3] Application prices per acre may vary within different regions of the United States.

the crop may be translocated elsewhere, greatly reducing the accuracy of application. The inaccuracy of application may cause harm to non-targeted vegetation communities, organisms, and rural communities.

Ground broadcast herbicide can be applied with mounted herbicide tanks on farming equipment (e.g. boom sprayers, tractors, ATVs, etc.) that can dispense herbicide during the operation of the vehicle. This method is commonly used due to the ease of implementation and access for farmers. The placement of the spraying apparatus is closer to the ground cover, increasing the foliar coverage and ensuring proper management of target species. Unlike aerial application, this method of glyphosate application can be very costly. Depending on the rate of discharge from the sprayer, the cost can range from $164 to $291[4] per acre (Tessier et al. 2010). Ground broadcast application can increase the risk of crop damage and soil compaction by introducing heavy equipment driven through fields, leading to a reduction in crop yields. If the wrong dilution of glyphosate is used for application, this method can lead to the translocation of glyphosate through the soil. This introduction of glyphosate into soil mediums with higher sand content can harm living microorganisms, lessening the probability of this chemical to be degraded (la Cecilia et al. 2018). On the other hand, there is a reduced likelihood of spray drift due to close proximity to the ground. This side effect is still prevalent when the proper weather conditions and specialized equipment are neglected, once again placing risk on environmental and anthropogenic factors.

Small-scale herbicide application equipment utilizes a tank that is either hand-held or strapped onto one’s back where a pumping mechanism is used to dispense herbicide. This method of herbicide application is frequently used for small patches of unwanted vegetation and/or places that cannot be reached with heavy machinery (Manning et al. 2011). The hand-held application method is not used at a large scale in agricultural settings because of the limited tank size. It is mainly used to treat patches of weeds along roadsides and infrastructure. This method has the highest risk of human exposure to glyphosate (Machado-Neto 2015), because of the close proximity of the applicator to the herbicide application site. If the proper personal protective equipment (PPE) is not used and permissible weather conditions are not accounted for, the probability of intoxication by herbicide will increase substantially. The risks and possible harm

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[4] Application prices per acre may vary within different regions of the United States.

of human herbicide exposure has been a controversial topic in the United States; within the past five years this topic has gripped the public's attention. The ethics behind the use of glyphosate will be addressed later within this report.

Glyphosate Resistance Case Study

Genetically Engineered Soy and Glyphosate-resistant Weeds

In the United States, over 119.5 million metric tons of soybeans were produced in 2017, encompassing about 35% of the world's soybean production (American Soybean Association 2018). In 2009, 91% of the total U.S. soybean acreage was grown with genetically engineered (GE) glyphosate-tolerant cultivars. The adoption of GE soybean production has led to an excessive use of glyphosate for weed control. This massive increase in glyphosate use is due to the ease and efficiency of application of this herbicide. However, the implementation of glyphosate-tolerant soybean seeds in the U.S. led to glyphosate resistance in weed species commonly associated with soybeans. In 2010, reports on glyphosate-resistant weeds indicated that there were 30,000 infested sites, covering approximately 4.6 million hectares in the United States (Meyer 2010). As glyphosate use increases within agricultural practices, the consequences of glyphosate-resistant weeds will become more prominent. As of December 2019, 47 documented glyphosate resistant species exist within the United States (Herbicide-Resistant…2019).

Herbicide resistance refers to the inherited ability of an individual plant to survive an application of herbicide that would typically kill a normal population of the same species (Peltzer et al. 2019). This phenomenon occurs when there is a repeated use of herbicides that share the same mode of action. These resistant weed biotypes are sourced from the basic evolutionary process where individuals that survive herbicide application will be able to reproduce, thus passing along the resistance to glyphosate to its progeny (Herbicide Resistance…n.d.).

The increased reliance on glyphosate use in the production of GE glyphosate-tolerant soybean crops led to the rapid evolution of glyphosate-resistant horseweed in 2000. This was the first mass instance of a broadleaf weed species evolving resistance to glyphosate in the United States (Boerboom 2016).

The increasing incidence of herbicide resistant weeds has created economic pressure on farmers. Unwanted vegetation species are taking over valuable cropland and reducing crop yields. However, to reduce the possibility of herbicide-resistant weeds, there needs to be diversity in weed management techniques. The tactics to help mitigate and manage glyphosate-resistant weeds include: utilizing herbicides with different mechanisms of action, incorporating adequate tillage practices, rotating crops between GE glyphosate-tolerant and/or resistant crops with crops that have other types of herbicide resistance, limiting the use of GE glyphosate-tolerant crops to when they have the greatest economic and management value, and avoiding the application of glyphosate to a field for two or more continuous years (Boerboom 2016). It should be noted that each practice has its own inherent benefits and detriments.

The introduction of glyphosate in 1974 provided an opportunity for farmers to efficiently manage weeds. The consequences of this chemical are becoming more apparent due to scientific research illustrating the repercussions of glyphosate use within agriculture. However, within the past five years, glyphosate has become controversial due to its potential of being a human carcinogen. This claim has not been confirmed by scientific evidence, but it raises concerns towards the ethical use of this herbicide.

An Introduction to Ethical Theory

The study of ethics and ethical practice is one which ought to be simple. Is an action, a speech, a purpose, good? That is, what does it mean to be Good? Inherently, we know Good when we see it. Feeding starving orphans is Good. Kicking puppies is Bad. And if the world were all puppies and orphans then the subject would end there. But of course, it isn’t and it doesn’t, so the study of right and wrong merits more attention.

Even the meaning of the word “ethics” varies depending on school of thought. An action is considered ethical...compared to what? Because the person is virtuous? Because it was their duty? A soldier who kills to protect their country may be in the ethical right because they are doing their duty, but ethically compromised because they killed another human. This paper will cover several ethical considerations, but primarily it will focus on consequentialist thought.[5]

Consequentialism is the school of thought which focuses on the consequences of any particular action. In simpler terms, it seeks to determine and quantify the positive and negative effects of any given event, relating both the immediate reactions and the degree to which

[5] It should be noted that these are solely the beliefs of the authors, and that the ethical portion of this paper will be up to debate. By its nature, ethics is a discussion, not a final product.

cascading effects are caused by the initial action. In mathematical terms, it takes a weighted average of all possible outcomes, determined by their value and their degrees of relation to the event. If that result is positive, the action can be considered "ethical".

Theoretically, we can calculate an "ethical limit", where the total ethical consideration of a given action approaches a positive or negative value, because resulting effects are progressively more removed from the initial action. This avoids the quagmire of discussion in which many philosophical arguments founder, but removes a certain degree of subtlety in argument. We are, unfortunately, dealing with large-scale issues and thus large-scale thought must be employed.

Considerations of This Paper

This paper focuses on glyphosate application and usage, so we must understand the participants involved in such discussion. Who are the primary users of glyphosate? Who benefits and who suffers from the use of glyphosate? How far-reaching are the effects of glyphosate application? This paper aims to narrow the broad spectrum of glyphosate effects into three stakeholders: Shareholders, Applicators, and the Environment.

The Shareholders are defined as those who have a vested monetary interest in the usage and proper application of glyphosate. The primary Shareholder is the german chemical giant Bayer—which acquired the Monsanto Corporation in June 2019—who produce Roundup (an herbicide composed of glyphosate). Additionally, this covers the farmers and corporations which use glyphosate in their business. These are the people purchasing the chemical and ordering it to be applied, the people who are ultimately responsible for glyphosate usage.

The Applicators refers to the group of people affected by exposure to glyphosate. This includes both the actual applicators and the workers in contaminated areas who may risk exposure. It is important to note that the degree of exposure varies significantly depending on individual company safety policies and precautionary measures taken.

Finally, the Environment refers to the ecosystem affected by glyphosate application. It is this stakeholder, and the risk associated, which the scientific portion of this paper has defined and assessed in great detail. This includes, but is by no means limited to: soil microbial diversity plant biodiversity, plant life history stages, water quality, aquatic invertebrate biodiversity, inter- and intra-specific dynamics, and ecosystem structure and function.

Cultural Responses to Glyphosate

Views on glyphosate vary significantly across the globe, often in relation to everyday use. A farmer in Montana is more likely to support the usage of glyphosate than a freshman at Berkeley (Bunge 2019). The production and application of glyphosate is expected to be an approximately $8 billion business by 2025 (Yenduri and Onkar 2019), and like any business of that size, it is bound to elicit strong viewpoints and influence. Groups like the Sierra Club[6] have made it their goal to oppose herbicide usage, arguing that unintentional consequences of glyphosate application could be disastrous (Price 2018). On the other side, companies like Bayer advertise their product as controlled and consistent.[7]

In a larger sense, the cultural dichotomy between the supporters and opposers of glyphosate (and other herbicide) usage can be better understood as a political one. The herbicide industry caters specifically to large-scale farming. As stated previously, 1.6 billion kilograms of glyphosate have been applied in the U.S. since 1974, mostly on large-scale farms. In contrast, the majority of opposers to glyphosate application come from backgrounds of higher education, in which interactions with the farmers themselves do not necessarily occur often[8]. It's not hard to see that the political differences between these stakeholders may lead to further opposition. In this country, the environment as a whole is a political issue, and thus the debate over herbicide is not only scientific, it is at least partially cultural.

Education is a big player in the glyphosate debate as well. Often farmers do not consult scientific literature when determining their farming methods. A "common sense" approach, where generational knowledge is passed down with little examination, is far more customary. On the other end of the spectrum, opposers of glyphosate may over exaggerate the potential ramifications out of fear. Very few people are prepared or willing to consult scientific literature when discussing such a controversial or sensitive issue.

From their own point of view, either end seems justified. Glyphosate is cheap, effective, and provides farmers with a vital and often underappreciated service. It is understandable that

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[6] The mission statement of the Sierra Club is "To explore, enjoy and protect the planet. To practice and promote the responsible use of the earth's ecosystems and resources; to educate and enlist humanity to protect and restore the quality of the natural and human environment; and to use all lawful means to carry out those objectives." They have been an active environmental organization since 1892.

[7] The Monsanto website is not specific as to the mode of action of their herbicides, specifically it is difficult to find any information relating to herbicide spread or leaching.

[8] This is of course a generalization and does not apply to every instance.

someone might ignore the unpleasant aspects of herbicide usage if it is fundamental to their livelihood. Alternatively, it seems not only justified, but vital that landowners oppose the application of a dangerous chemical on an already overstressed body of soil.

Clearly, neither argument is “right”. Both suffer from a lack of nuance, either from not understanding the potential ramifications of herbicide leaching and genetic resistance, or from a cultural fear of chemicals and the companies that produce them. This section seeks to examine both viewpoints and to parse out the ethical and scientific considerations that should be undertaken when dealing with glyphosate.

Ethical Considerations of Glyphosate

In June of 2018, a California school groundskeeper named Dewayne Johnson took the Monsanto Corporation to court over allegations that exposure to their product, Roundup, caused him to develop non-Hodgkin's lymphoma, a disease which he is currently dying of. The suit was originally for $289 million, of which he was awarded a reduced settlement of $78 million (CNN n.d.). At that time, there were over 4,000 open cases awaiting trial for similar accusations. As of October 2019, there are over 42,000 (Springer 2019).

In environmental science, we consider both the importance of human and environmental impacts. We cannot ignore the ethical considerations of glyphosate on those exposed. Although there has been no significant linkage between glyphosate and cancer in humans (Mink et al. 2011), misuse of herbicides can pose a risk to farm laborers. It is not only the ecosystem which can be put at risk.

Ethical Concerns with Human Exposure

Most herbicides are designed to affect only plants, using such pathways as do not exist in human biology. This includes photosystem inhibitors, enzyme production inhibitors, and many other plant- (and even species) specific modes of action. Glyphosate targets a metabolic pathway that does not exist in humans. However, because of the nature of the product, and the complexity of the system in which it is applied, there are unforeseen consequences. In the case of Roundup, that may include cancer.

Herbicide application can take several forms, by airplane, tractor boom, or by hand. Aerial and tractor application have relatively low risk to the applicator, who is protected by a cab. Hand-spraying puts the applicator in a much higher risk of herbicide exposure. Most herbicides have a certain minimum safety gear that is required to apply them. This is at a minimum long pants, long sleeved shirts, gloves, and closed-toed shoes. Depending on the herbicide, the required safety gear may be as extensive as to include a particulate respirator and chemical apron. Notably, the EPA Worker Protection Standard (WPS) has been criticized for being out of date and insufficient (Exposed and Ignored…2013). For instance, the herbicide chemical label for Paraquat requires a respirator to be used, but given the mode of action (lipid synthesis inhibitor) and the extreme danger it poses to humans, this appears minimal at best.

Though the risk from hand-spraying is often highest to the applicator, the risk from boom spraying may fall to workers in the fields which have been sprayed. Herbicide residues can remain volatile for hours, risking absorption in human skin or through pulmonary passages. This risk is especially high for under-privileged workers, specifically migrant laborers or undocumented immigrants working in agriculture fields. This section of the U.S. population is routinely overlooked (Arcury and Quandt 2003). A report by Farmworker Justice found that farmworkers are regularly exposed to toxic levels of pesticides, a practice which is made possible by out-of-date regulations and unsupervised farming methods (Farmworker Justice 2013). Additionally, many migrant workers' homes are situated close to the agricultural fields they work, meaning that exposure is not limited to the workers, but also to their children (Salvatore et. al. 2008).

Ethical Considerations in Application

We must also consider the ethical issues involved in application precision and amount applied. This includes possibilities like over-spraying, killing desirable species, and herbicide drift. Though these problems may seem minor in comparison to human exposure, improper application of herbicides may damage already fragile ecosystems or lead to herbicide resistance in weed species. Often, the precision comes down to company application procedures and how strictly they are enforced. Herbicide labels include directions for application, but the degree to which these are practiced varies. Ethically, it is important to cause as little harm as possible, both to the environment and to humans. Therefore, it is important to apply herbicide carefully and responsibly. For example, this includes avoiding spraying in high winds, spraying before rainfall, and focusing on undesirable species.

This brings up the fundamental problem of collateral damage. Herbicide drift can cause significant harm to the wild-agriculture interface without providing any benefit. Especially in already damaged systems, herbicide drift from fields can disrupt ecological balance.

Discussion

The use of glyphosate is a scientifically and ethically complex issue. At some level, the risks posed by glyphosate are similar to those posed by all herbicides, namely genetic resistance and human or environmental impacts. The singularity of glyphosate comes from its widespread usage. Crop science has progressed with the use of glyphosate in mind, focusing on making its use easier rather than devising new herbicides. The question is now a cultural one, how do we change weed management practices to reduce chemical control frequency.

Many weed management controls exist and have been extensively studied, from biological control to the physical removal of weeds. Chemical control has maintained its popularity primarily due to the low cost of application, labor, and high rates of efficacy. Additionally, the ecological cost of routine herbicide application remains poorly understood to many agricultural businesses. Therefore, it is not surprising that herbicide usage is so common, but the problem—ecological and anthropogenic damage— remains. Though rotation of different group herbicides will diminish resistance, eventually genetic alteration and recombination will result in broad-spectrum tolerance. This is a serious problem which is being largely ignored, but as with many scientific issues, the solution falls to education. Broad public campaigns covering alternative strategies could reduce herbicide usage. Due to the higher cost of alternative strategies, government subsidies could be implemented. The common complaint is that the costs are then passed on to the taxpayers, but given that this is a problem which affects all of us, that seems an acceptable price.

In weed management, often a “many little hammers” approach works best, where several different controls affect weed growth in different ways. This falls under the umbrella of integrated pest management, a theme which is gaining traction in the agricultural and scientific communities. However, the most promising frontier in combating herbicide resistance will come from new and unexplored ideas. These include gene drives to reduce weed fertility, cultivating and disseminating herbicide susceptible species, and the implementation of other cultural controls. The future of weed management is steeped in learning from our past mistakes.

We must also consider future endeavors for ethical treatment towards applicators and field laborers. This must follow a nationwide attitude shift towards how we view our workers' rights. As the Chicano movement[9] did in the 1960's, so we must now reassess the state of farm labor in the 2020s. This means we must increase supervision of farms, especially those which employ minorities and at-risk communities. Concurrently, herbicide production companies have an obligation to correct and re-analyze their product labels. This includes more prominent warnings and increased requirements for personal protective equipment.

Herbicide companies must be held accountable for their actions, but that will only help with portions of our current problems. Community involvement has been shown to be instrumental in disseminating scientific information, so we as a scientific body should focus on including community participation in our work. Ultimately, this is an issue which is solvable, but will require immediate attention from all involved parties: the farmers, the scientists, the politicians, and the corporations. We all have a part to play.

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[9] From the 1940s to the 1970s, Mexican-American activists fought for immigrant worker's rights. Led by Cesar Chavez and Dolores Huerta, this movement resulted in the United Farm Workers Union, a huge leap in farm laborer rights and power. The movement was termed the "Chicano Movement", or "El Movimiento"

8. Energy

8a. The Ethical Implications of Climate Change in the 21st Century

Hailey Webb

Climate change is a controversial topic that is grossly misunderstood by the general population and tortured relentlessly by politicians in the United States. To the average person, climate change is either something you believe in but avoid talking about or an elaborate hoax created by leftist politicians to forward a personal agenda. To a scientific audience, climate change is spoken about as fact. Scientists define climate change as "a change of climate that is attributed directly or indirectly to human activity, that alters the composition of the global atmosphere, and that is in addition to natural climate variability over comparable time periods." (UNFCCC 1992). Scientists are trying to understand more about climate change's implications and predict what the world will look like in ten, twenty, fifty, or even a hundred years from now if the average global temperature continues to rise (Collins et al. 2013).

Most current climate models estimate that the average global temperature will rise between 2.3 ℃ and 6.3 ℃, with a high of 4 ℃ extremely likely assuming a worst-case emissions scenario (IPCC 2007). Representative Concentration Pathway (RCP) 8.5 represents a worst-case scenario projection model where emissions will continue to rise throughout the 21st century (Meinshausen et al. 2011). Unfortunately, an RCP 8.5 is very possible since annual global greenhouse gas emissions are still increasing in countries with the highest emissions (Marland et al. 1985). While a low estimated temperature rise of 2 ℃ may seem miniscule to some, a warming of this magnitude could result in alarming global changes in the next century (Friedlingstein et al. 2014).

In the western Americas, climate change is projected to cause warmer, wetter winters and drier summers, resulting in longer fire seasons and higher fire intensity (Veblen et al. 2003). As urban sprawl becomes increasingly common in areas vulnerable to fire, more people are putting their lives and homes at risk (Radeloff et al. 2005). Just from 2016 to 2017 alone, wildfire losses in the United States went from approximately $2.5 billion to well over $18 billion dollars (National Interagency Fire Center 2018).

As atmospheric greenhouse gas concentrations continue to rise, the world's oceans attempt to correct the imbalance. Most anthropogenic carbon dioxide (CO_2) in the atmosphere is absorbed by the oceans. In fact, 40% of CO_2 emissions since the beginning of the industrial era have been absorbed by the planet's oceans, and recent data reveals that within the last decade, oceans have increased their rate of CO_2 uptake (Devries et al. 2017). The reaction of CO_2 with water and carbonates (CO_3^{2-}) results in bicarbonate ($2HCO_3^{-}$) which eventually dissolves out into hydrogen ions. Hydrogen ions increase ocean acidity, making carbonate less available to calcifying species like clams, oysters, corals, and pteropods (Gattuso and Hansson 2011). Severe levels of shell dissolution in pteropods have already been found in the Southern Ocean (Gardner et al. 2018). Pteropods are critical in the ocean food web, and the decline of this species from ocean acidification could have disastrous ripple effects throughout the entire ocean ecosystem (Gardner et al. 2018).

As average global temperatures continue to rise, so does the temperature of the planet's oceans. Warmer ocean temperatures are causing a mass extinction of coral reefs. When the water is too warm, corals expel the algae (zooxanthellae) that live in their tissues, a process known as coral bleaching. These zooxanthellae are responsible for the bright colors of corals, so when they are expelled, the coral is left white and void of life (Wicklund et al. 1988). This massive coral reef die-off was not noticed by scientists until the 1980s, and it could have huge implications on many ecosystem services that humans rely on (van Oppen et al. 2009). Coral reefs protect our coastlines from rough waves and intense tropical storms. They are also responsible for bringing in large amounts of revenue from the fishing industry. Australia generates more than $1.5 billion every year from its fishing industry thanks to the Great Barrier Reef (Prayaga et al. 2010).

Not only are the oceans getting warmer, but sea levels are also rising (Jones 2013). Melting glaciers and ice sheets as well as thermal expansion are to blame. The Intergovernmental Panel on Climate Change (IPCC) states that oceans have risen around 3 mm annually since the 1990s, and they predict between a 0.75 m and 1.9 m rise by 2100. If these predictions are true, an estimated 4 million people worldwide will be in areas of heavy annual flooding or displaced entirely from their homes in just the next 80 years (Vermeer and Rahmstorf 2009).

This new era of climate change is more like a climate crisis. Millions of people worldwide are going to have to change their way of life to adapt to a changing climate. For many, it is incredibly frustrating to understand the science but watch as political leaders refuse to take policy action to mitigate climate change and cut emissions. The younger generation, in particular, is questioning the ethicality of leaving future generations with an unsustainable planet. America's youth became so fed up with the lack of concern for climate change that in 2015, a group of twenty-one teenagers from Oregon decided to sue the entire United States government. Their lawsuit alleges that the government knowingly failed to protect them from climate change (*Juliana v. United States*). Their argument states that the government is in violation of the due process clause of the Fifth Amendment of the U.S. Constitution, which states that "no person shall be deprived of life, liberty, or property, without due process of law" (U.S. Const. amend. V). The consensus among scientists is that CO_2 levels in the atmosphere must be stabilized at or below 350 million parts per million (ppm) to protect the current climate system (Azar et al. 2010). The planet's CO_2 levels are now currently 410 ppm which is likely the highest level in Earth's atmosphere in the last 3 million years (Willeit et al. 2019). The Defendants claim that the Plaintiff (U.S. government) has infringed on their fundamental constitutional rights to equal protection because they have known about the dangers of high CO_2 levels in the atmosphere but neglected to take action (*Juliana v. United States*). At first, many people dismissed this case and viewed it as a group of teenagers seeking national attention. However, this court case is still ongoing. United States District Judge Ann Aiken even stated, "Exercising my 'reasoned judgement,' I have no doubt that the right to a climate system capable of sustaining human life is fundamental to a free and ordered society" (CBS News 2019).

Some members of the House of Representatives decided to do something to address many American's concerns about climate change. In February 2019, 18 Democratic members of Congress proposed a piece of legislation titled the Green New Deal (H. Res. 109, 116th Cong.). The document is purely symbolic, standing at only 14 pages long and proposing an economically infeasible plan. However, it is an important first step in promoting discussions about how to eventually become a net-zero emissions economy. The IPCC came out with a report last year stating that the world has twelve years to massively change global energy infrastructure in order to limit disastrous impacts of rising average global temperatures (IPCC 2018). Assuming the predictions are true, the Green New Deal was crucial in getting American leaders to think about ways to implement new climate-friendly policies.

Unfortunately, on November 4, 2019, U.S. President Donald Trump formally began the process of withdrawing from the historical Paris Agreement which aimed to lower global greenhouse gas emissions (Beitsch 2019). The climate crisis only appears to be getting worse, and this news came as a shock and a defeat for many. A report from the Fourth National Climate Assessment shows data supporting evidence that climate change is happening much faster than predicted (Wuebbles et al. 2017). The time to mitigate the impacts of climate change is running out, and younger generations all over the world are depending on political leaders to ensure them a safe and sustainable future.

Although there has been a disconnect between scientists and politicians in the past, the future of the planet depends on these two parties working together to solve the climate crisis. It is seen as an ethical conundrum for many who believe that scientists should stick to science and stay out of politics. Many fear that if scientists get involved in politics, science will be inherently biased. For example, a scientist that advocates for more climate change legislation might be influenced to only gather data that shows the worst possible impacts of climate change. While this is a valid concern, the peer review process for publishing scientific papers is extremely thorough. A paper is peer reviewed by other scientists in the same field and edited dozens of times for quality control before it gets approval to be published.

Science should be at the heart of environmental policy decisions since it is based on fact. Scientists are experts in their field and have a better understanding of ecological systems than anyone else. However, publishing scientific data and neglecting to share it on a political level is not only irresponsible, but unethical. Climate scientists understand the urgency of the climate crisis, and it is their responsibility to communicate their findings with political leaders. It is then the duty of politicians to trust the scientists and design policy that reflects this urgency. Scientists and politicians have failed miserably at this process, and both parties need to have better communication if there is any chance of reversing the damage humans have caused. To combat the climate crisis of the 21st century and ensure a sustainable future for all people, there needs to be a global agreement that climate science should dictate policy.

8b. The Global Imbalance Associated with Consumption and Carbon Footprints of Nations

Charles Dickson

The world is unequal. We live in a world that has varying levels of wealth, safety, and growth within and across nations. The Industrial Revolution began in Britain in the eighteenth and nineteenth centuries and was a time in which economic growth pushed millions of people out of material deprivation (Deaton 2013). This led to what is known as the "Great Divergence" when northwestern Europe and North American followed Britain in this time of growth and left the rest of the world behind (Deaton 2013). The divergence caused a large gap in economic growth between nations which caused the inequality we see today.

A significant contributing factor to the development that led to nations such as the United of America to move ahead of other countries is the shift to the once abundant non-renewable energy resources such as coal. The use of cheap energy such as this, is a direct contributor to the extensive growth these nations were able to achieve during that time period. By the mid 20th century, the anthropogenic causes leading to climate change were made clear. As seen in Figure 8.1, the carbon dioxide levels in parts per million shoots above the historic average atmospheric

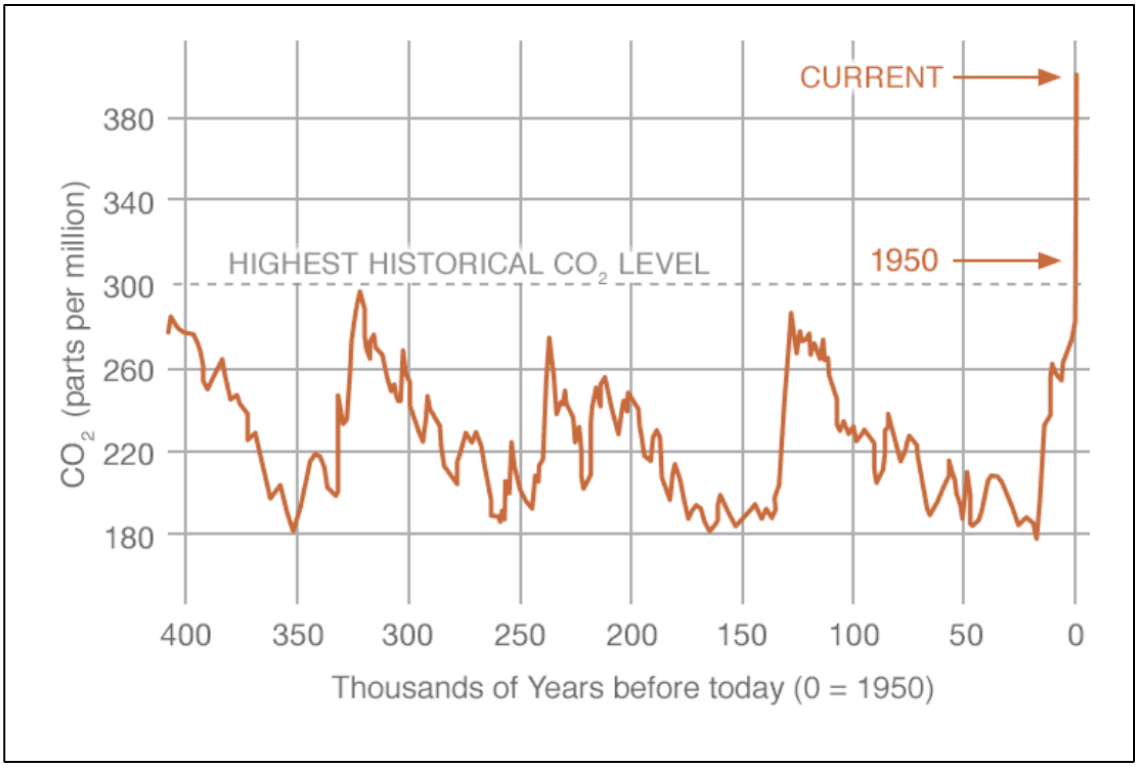


Figure 8.1: Carbon dioxide levels derived from ice core measurements from years before today including the current level.

carbon dioxide levels in 1950. This is after the industrialization boom that occurred in the 18th and 19th centuries and carried through to our modern time. This data shows that anthropogenic changes in our world has led to a drastic climate change, our recent history has never seen.

The Intergovernmental Panel on Climate Change made the statement, “Taken as a whole, the range of published evidence indicates that the net damage costs of climate change are likely to be significant and to increase over time” (Jackson 2018). Clearly, climate change is an issue impacting everyone on our planet whether everyone notices it day to day and the effects are and will continue to be serious. Given the variance in geographic locations of and uneven distribution of industrialization across nations, the risks associated with climate change are not shared.

The global imbalance associated with consumption and carbon footprints amongst nations can be observed in a few different ways. One way is to assess overall carbon emission outputs across countries. In Figure 8.2, the comparison of gross domestic product per capita plotted against carbon dioxide emissions per capita in every country. In this figure circle size represents relative population size to each other. In the graph we see developed countries such as the U.S., with a GDP of 53,015 International dollars and carbon dioxide emissions per capita of 16.48 tonnes (Maddison 2017). This can be compared to a far less developed area such as the African country Mozambique that has a GDP per capita of 1,113 international dollars and emissions of 0.34 tonnes of CO2 emissions per year (Maddison 2017). This graph clearly shows that as GDP increases the carbon dioxide emissions increase. This positive relationship between overall higher income and economic well-being versus emissions on average per person show unequal distribution of who is contributing to climate change.

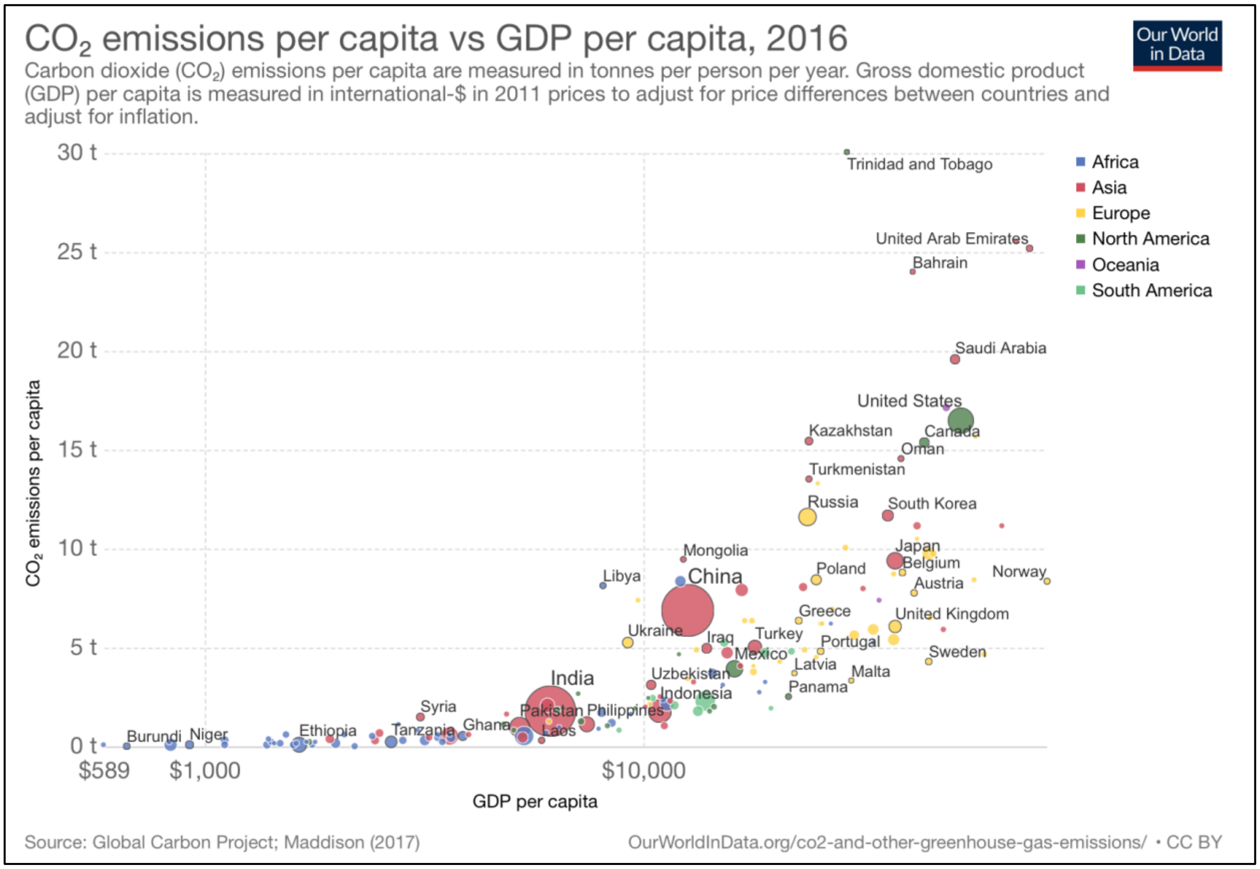


Figure 8.2: Relationship of carbon dioxide emissions per person in each country versus gross domestic product per person.

A similar way to compare countries in terms of development and carbon footprints is to compare them using the Human Development Index (HDI). The HDI is used by the United Nations to assess countries' overall development without relying on an economic parameter (Human Development… 2019). The index measures a country's achievement based on three parameters: having a long and healthy life, a decent standard of living, and being knowledgeable. There are numerous statistics that go into forming these parameters and creating a measure that accurately represents the development of a nation overall. In Figure 8.3, the graph compares ecological footprints of countries measured in global hectares per capita against the HDI from data compiled from 2005 data from the 2008 report for the Global Footprint Network. There are developed countries such as the U.S., Australia and Canada over consuming. Countries above the red line, plotted on the y-axis, indicates that they have met the standard for high human development and countries to the right of this line means they have a higher carbon footprint than the earth can support. The countries plotted to the right of the Earth's biocapacity and above the threshold for high human development are overconsuming and negatively impacting out earth. The countries plotted to the left of the line indicating Earths biocapacity, and below the 0.8 threshold, are living within the earth' means to support life yet have not yet met the standard for high human development. This indicates that they are under consuming. If every country could fall into the green square, we would be meeting the minimum criteria for worldwide sustainability by living within the earths capacity and maintaining high human development.

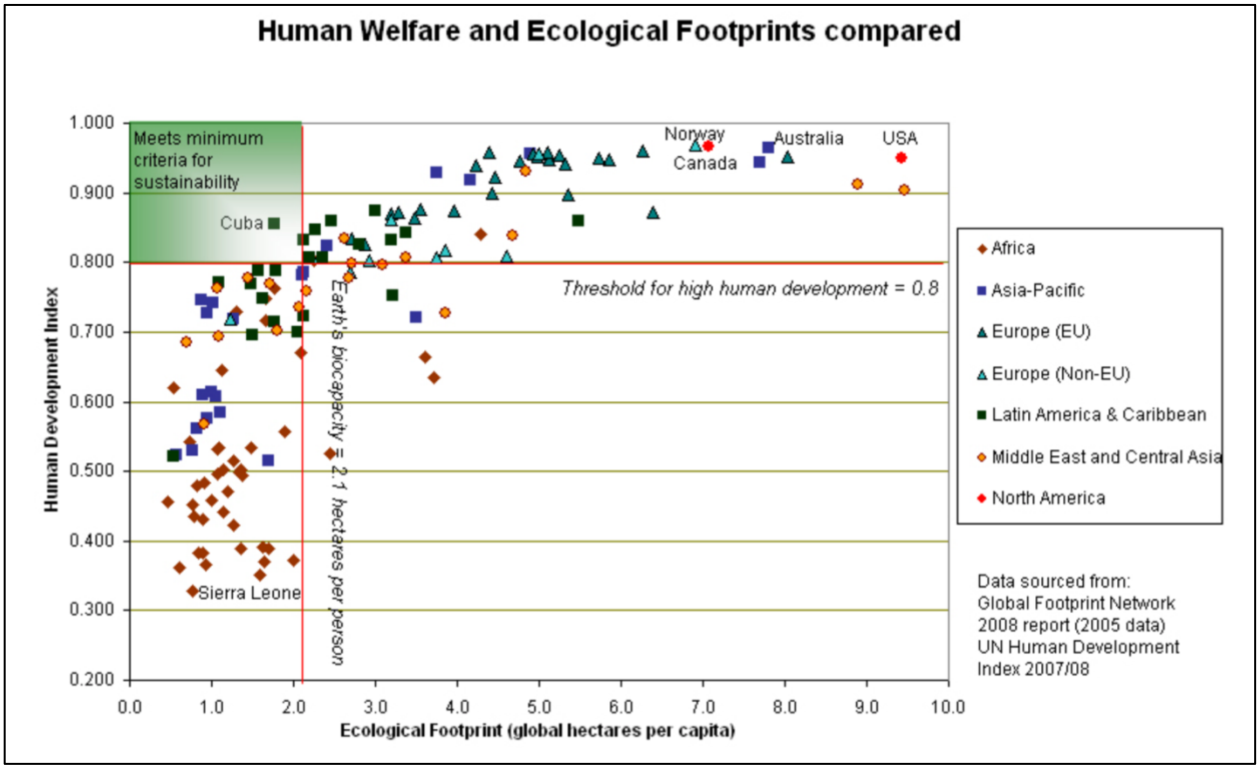


Figure 8.3: Graph depicting the relationship between the Human Development Index and Ecological Footprint.

In 2016, the top three countries that had the largest carbon footprint were China, the Unites States of America, and India. They emitted 9056.8, 4833.1, and 2076.8 megatons of carbon dioxide respectively (Renewable Energy…2019). These countries combined account for 52% of the worlds carbon emissions (Each Country's… 2019). This statistic shows that over half of the carbon emissions that are warming our earth is generated from only three countries.

In the Global Climate Risk Index (CSI) for 2019, written by Eckstein et al., analyses the severity and outcomes of weather-related loss events such as storms floods, and heat waves that all come in wake of the changing climate. Each of the 10 countries ranked on the current 2017 CSI and long-term CSI (1998-2017) are developing nations. The top three countries in 2017 with the highest CSI are Puerto Rico, Sri Lanka, and Dominica receiving scores of 1.50, 9.00, and

9.33 respectively. The CSI is derived from the following factors; number of deaths, number of deaths per 100,000 inhabitants, sum of losses in U.S. dollars in purchasing power parity, and losses per unit of Gross Domestic Product (Eckstein et al., 2019). This risk assessment shows that there are countries at far greater risk of the effects of climate change.

The countries with the largest carbon footprint have a much lower risk towards the effects of climate change on the basis of the CSI. China, the U.S., and India have far greater populations so it makes sense that they would have more carbon dioxide emissions than a country like Dominica, with a population of around 72,000 (The World Bank 2018). However, these more developed countries have a significant influence on the world climate and must be held to some degree of responsibility for the degradation and danger that is being put on others.

There are numerous facets to the climate change issue that could be adjusted in order to make a positive change on our earth’s climate. One way is to focus on the energy sources that got our world to the highly industrialized and developed state it is. Studies show that there is a causal relationship between energy consumption and economic growth in developed countries (Dinçer 2017). The vast development our world has seen since the eighteenth century has led us to the crisis we are in.

Focusing on the sources and ways in which countries’ growth is fueled, will be key to helping the world mitigate climate change in a way that helps those that need it the most. Cleaner energy is necessary to do this. There are currently five categories of renewable energy; biomass, hydropower, geothermal, wind, and solar (Renewable Energy… 2019). It is up to our nations to implement these energy sources in a way that helps the climate, and in turn help the people. Implementing these practices will help to fuel on-going development in developed nations and spark sustainable growth in developing nations in order balance out all nation’s impacts on the environment.

8c.

Albert Craig

As we transition to a world with renewables energies, it is imperative to examine who will profit the most. It is important to examine this for a few reasons. First, excess profits from our current energy system, mainly in oil and natural gas sectors, have promoted the exploitation of land and peoples. Second, many of the proposed renewable energy sources directly affect the public, whether it's nuclear energy and radiation, windmills and harmful frequency, or hazardous waste from solar panels. Ethically we need to decide whether the profits from energy go entirely to the energy companies. Oil and natural gas have generated immense profits, in most countries these profits have gone directly to the oil and gas companies, but some decided to set aside portions of this profit to be used for a public fund. These funds are known as sovereign wealth funds, and are comprised of stocks, bonds, property, and other financial assets purchased with excess profits from oil or another natural resource. By taking one source of income and placing into a sovereign wealth fund with a wide range of financial instruments, you are diversifying and taking less risk. This can help countries that depend on one or two natural resources to generate profits because it helps to protect them from a market crash in the natural resource that they produce.

One of the best examples of a sovereign wealth fund is Norway's Sovereign Wealth Fund, also known as Norway's oil fund. Norway is a significant producer of oil and decided in 1996 to use a sovereign wealth fund for excess profits generated from oil. The idea behind Norway's sovereign wealth fund, and other similar sovereign wealth funds, is to accumulate wealth for when oil and gas reserves run out. Since 1996 Norway's sovereign wealth fund has become, one of the world's biggest investors in stocks, owning shares in over 9000 companies worldwide including Apple and Microsoft (Harris n.d). As of October 25, 2019, "the value of Norway's sovereign wealth fund grew to a record 10 trillion Norwegian crowns, or $1.09 trillion USD." (Solsvik 2019) If this $1.09 trillion was cashed out today it would roughly equate to $200,000 for every citizen in Norway. Money from this fund helps to pay for many of Norway's social programs, such as healthcare and education, which rank among the top in the world.

An example of a sovereign wealth fund within the United States is the Alaskan Permanent Fund. The Alaskan Permanent Fund was instated in 1976 and is similar to the Norwegian sovereign wealth fund in that it is primarily funded by oil profits. It requires that at least 25 percent of all mineral lease rentals, royalties, federal mineral sharing payments and bonuses received by the State shall be placed in a permanent fund (APFC, n.d). The Alaskan permanent fund is also similar to other sovereign wealth funds in that it invests heavily in stocks and other financial assets. The Alaskan Permanent Fund has invested heavily in companies within the United States, which has allowed it to benefit not only the people of Alaska, but also those in the rest of the United States. In recent years, however, there has been controversy surrounding the fund, in 2015 plunging oil prices created major shortfalls in the state's budget (Sundlee 2019). In response, then-governor Bill Walker slashed the annual check from $2,052 the previous year to $1,022. To raise the annual payout back up to its previous level, the next governor cut funding drastically to public broadcasting, Alaska's critical ferry system, Medicaid, and University of Alaska funding. These changes are partially due to the falling oil revenues in Alaska, but it is more due to poor governing of the state's budget and financial assets.

Other systems similar to sovereign wealth funds exist within the United States, and around the world. One example in the United States is the Department of Natural Resources, which sells the timber rights of public lands in exchange for funds for education. Many in Western States argue against this practice, and for good reason. There is a much greater cost benefit to maintaining public lands and leaving them open to recreation. Also, the timber sales usually do not equate to much funding for schools. In Washington State for example, Department of Natural Resources timber sales contribute $120 million to the state's education budget (Hutchins 2015). There are also examples of controversial timber sales around Bozeman, one recent one being on land southeast of Bozeman. The sale of the timber to a timber company was blocked after a group known as the Save Our Gallatin Front won the bid for the land with $400,000 and placed a 25-year conservation license on all 443 acres of the state trust land (Wright 2019). Public land in this country can also be seen as a natural resource. As seen in this example, many people in the greater Gallatin area saw preserving this state land as more important than money from timber sales. Public lands are usually more valuable as a source of recreation and natural beauty than any resource that can be extracted from them.

Another largely publicly owned natural resource in the United States is water. Water systems are both publicly and privately owned, but, 33 of 52 states and territories have more public that private water systems, and 50 of 52 states have a larger portion of their population served by public rather than private water systems (UNC, 2016). Public water systems have been beneficial in a few ways. First, having public water systems allows for regional governments to have control over their own water supply. Having the water supply in government hands allows for more transparency and local insight into their own water. Also, public water systems in the United States are generally cheaper than private water systems. One study found that, privately owned water systems charge 59 percent more than publicly owned systems (FAWW, 2016). Public water systems are a perfect example of successful public ownership of a natural resource.

Mining has remained private in the United States, but not the entire world. One of the countries that have nationalized their mining is Bolivia. In 1952, Comibol was created, and at the time was the world's second largest tin company. Most of Comibols operation was closed by 1986, with more private mines coming into play. Mining in Bolivia was re-nationalized in 2007 when President Eva Morales was elected to office. This nationalization upset many investors in Bolivian mining in the United States and the rest of the world. What Eva Morales had to say of this was, "we are discussing some deep reforms that will allow investors to recover their investments, but they are also going to have to make an economic contribution to the state, we need partners not masters." (Benson 2007) Bolivian mining has become important in recent years because of its large lithium reserves. Lithium is used in the batteries of electric cars. Firms from all over the world, including Tesla, have shown great interest into taking a stake in Bolivian lithium. President Eva Morales refused to work with foreign companies interested in Bolivia's lithium unless they agreed to partner with the Bolivian national mining firm. As of November 10th, 2019, President Eva Morales was overthrown by a military coup. In the weeks following this coup Tesla's stock rose nearly 55%, an astronomical value (Prashad 2019). One can only speculate that this rise in stock is backed by the assumption that the new military government of Bolivia will un-nationalize the mining companies and open up to more foreign investment.

Public ownership of natural resources in the United States is not new. We have seen public ownership of natural resources in the timber industry, water, and land. In order to survive as a society, we must make the switch away from oil and to renewable sources of energy in the near future. The energy generated from renewable energy sources will be sold for immense profits and placing portions of these profits into a sovereign wealth fund could benefit every individual in this country. It could be beneficial by providing more funding to everything from education to healthcare and giving the public more input into how our energy is produced. We have already seen this have success in the United States with the Alaskan Permanent Fund, so it is very possible to do it on a national level. In terms of ethics I believe that the ethical thing to do is nationalize or partially nationalize our energy production. We are running out of time to stop the full effects of climate change, and oil and gas companies will not willingly stop or slow their production. Through partially nationalizing or creating some sort of sovereign wealth fund we could use profits from oil and gas to help to transition to a future with renewable energies.

8d. Exploring the Potentials of Biofuels as an Alternative Energy Source

Eric Healy

Humanity has made use of biomass fuels as early as 171,000 years ago (Aranguren et al. 2018). Wood has been burnt as a source of heat and food preparation for thousands of years, with the first evidence of coal being used as a fuel in 1000 BC (McLamb 2011). It was the Industrial Revolution in the mid-1700s that spurred the large-scale transition from wood and coal to fossil fuels as humanity's primary source of energy. This period was tied to a major increase in the global population, which further increased the need for more large-scale energy sources (McLamb 2011). With coal being easily accessible and occurring in seemingly infinite supply, factories and industries around the globe transitioned their boilers and furnaces to burn coal. Coal powered the railways of the world and fueled the first World War. But in the mid-20th century, the world began to shift towards hydrocarbons, specifically oil and natural gas as the common-place fuels (Melsted 2018). It's this change that has had the most prevalent effects on both the world's climate and pollution.

As of 2018, the United States uses approximately 30 trillion cubic feet of natural gas per year, which makes up 31% of our "primary energy consumption" (Natural Gas Explained… 2019). This is paired with 7.5 billion barrels of oil per year, which makes up 36% of our "primary energy consumption" (Oil… 2019). Oil/petroleum-based fuels (diesel, gasoline, jet fuel, etc.) are used heavily in powering all forms of transportation, which contributes more greenhouse gas emissions than any other sector in the US, at 29% annually (Sources of Green… 2019). Every segment of the transportation industry has worked to improve their fuel efficiency to both reduce their operational costs and to abide by new regulations passed down by governing bodies. But traditional internal combustion engines are limited by thermal efficiency issues that cap gasoline-burning engines around 35-40% efficiency and diesel-burning engines around 60% (Goldenstein 2011). And this is where solutions like biofuels come into play.

Biofuels are liquid fuels such as ethanol and biodiesel that are derived from natural sources. (Biofuels Explained… 2019) Most often these fluids are mixed with gasoline or diesel to reduce the consumption of the oil-derived fuel.

Generally, biofuels are derived from crops like sugar cane, corn, and soybeans, but more exotic solutions have been proposed with algae, wood byproducts, and food waste (How Biofuel is Made… 2017). The process begins by breaking down the choice source of biomass into its chemical components, utilizing a combination of extreme temperatures, pressures, and chemical aids. This results in a form of bio-oil that requires further refinement to be made useful. This refinement often comes in the form of fermentation, resulting in an alcohol-based product like ethanol or biodiesel (Nunez 2019). Ethanol can be mixed with gasoline to reduce gasoline consumption and emissions. Biodiesel is considered a ‘drop-in’ fuel that does not need to be blended with conventional diesel (Nunez 2019) to be usable.

The biggest advantage of biofuels is the wide variety of source material they can make use of. Things that would otherwise go to landfills, like food waste and wood byproducts can be turned into fuels after being put through the break-down and refinement processes. Making use of these sources means less need for oil drilling and exploration, which also reduces the chances of environmental damages and habitat loss (Scheer 2013). But the current methods of turning these products into usable sources of fuel aren’t efficient enough to generate a quantity and quality of fuel that could serve as a potential replacement for large scale fuels like petroleum (Food Waste to Biofuels… 2019). This brings up the need for more biomass, and where this biomass would come from. Agricultural land in the US has been declining since the middle of the 20th century (Nickerson 2012), while the population has steadily increased. With more mouths to feed and less land to cultivate, the stress on farms increases, making it difficult to take a portion of what fertile land is left and using its yield for power generation instead of food. This leads to ideas about changing western diets and reassessing food production strategies, both of which would require major cultural shifts.

With the need for more biomass comes the need for water. The growing, processing, and refining of biofuels consumes a large amount of water: in one liter of biofuel requires approximately 2,500 liters of water (820 liters for irrigation). And to implement all current US biofuel policies and plans it would take approximately 30 million hectares of cropland and 180 km^3 of additional irrigation water (Fact 7… 2014). This problem gets magnified by the threats of climate change and the increasing frequency and intensity of droughts in the US (Folger 2017). Finding a way to redirect water to generate enough biofuels will require cutting water from other sectors and/or greatly increasing water use efficiency on a global scale.

Because biofuels are being designed to be used in the internal combustion engines of today, little infrastructure change would be necessary to implement them on a large scale (Gent

2017). Gas stations could be retrofitted to offer ethanol and biodiesel, and minor changes can be made to a car's fuel system to allow it to burn either one. Biodiesel improves lubrication in traditional diesel engines, but performs poorly in cold conditions, compared to straight diesel (Ciolkosz 2016). Biofuels can reduce the consumption of fossil fuels and have the potential to improve the efficiency of internal combustion engines. While this is a step towards cleaner, more renewable energy, it doesn't remove the threat that emissions pose and doesn't completely remove fossil fuels from the equation. In the US, widely-available gasoline contains between 8 and 10 percent ethanol by volume (Biofuels Issues… 2012), which reduces the hydrocarbons in exhaust, but at the expense of less energy content in the fuel (Demirbus 2009) which, in turn, reduces mileage.

Biofuels have the potential to be a stepping stone to reducing our carbon footprint and moving away from fossil fuels without making drastic changes, but they don't currently provide a long-term solution on a large scale. The ingredients required to make biofuels a significant percentage of the energy sector are simply not available unless improvements can be made to the efficiency of the creation process.

8e. Ethical, Environmental, and Economic impacts of Wind Energy

Jacob Martin

The problem of climate change is a concern for scientists and non-scientists alike. While most scientists take a systematic approach to climate change and hope to understand the problems that arise, the public does not follow this approach. There has been a call for support for decreasing dependency on fossil fuels and increasing our renewable energy production. Renewable energy sources can include solar, nuclear, wind, hydro, biofuel. It is a common misconception that all of these sources of energy are all safe and provide clean energy in place of fossil fuels. However, each type of renewable energy still produces waste and has environmental impacts. The intention of this paper is to review the positive and negative impacts of wind energy on the environment and humans. For the purpose of this study, I broke the impacts into three categories: ethical, environmental, and economic issues. While environmental and economic issues drive policy, ethical issues are still important to consider. The paper will also provide basic technical information regarding wind turbine energy production.

Technical Information.

To understand the impacts of wind energy, you must have a basic understanding of the units that energy production and use are measured in. Production capacity is measured in Megawatts (MW), which is equal to one million watts. This unit is used to describe the maximum capacity of energy production from a wind farm. When a turbine is labeled as a 3 MW turbine, that means its production capacity is 3 MW at maximum production. When publishing energy production, the energy may be labeled with MWh, or Megawatt hours. In common terms, one million 1-Watt lightbulbs would use 1 MWh for every hour they are turned on. If a turbine with a capacity of 1 MW produced energy at full capacity for 1 hour, it would have produced one Megawatt hour of energy. However, wind turbines rarely produce energy at full capacity. The national average production for wind turbines is 25% of capacity (FAQ-Output). While this may seem small, the number of wind turbines in the country still accounts for a significant amount of energy produced. In 2015, the wind capacity in the United States was 74,471 MW, and the amount of energy produced by wind turbines was 190 million MWh (AWEA 2016, GWEC 2015).

Economic Implications

Many small communities have long been in financial crisis and are usually the target for wind energy developments. Developing new sources of wind energy can bring jobs during the construction phase, and a still significant amount during the operation and maintenance phase. A development in Texas provided 4100 construction period jobs, and 350 jobs annually (for the operations and maintenance phase) (Slattery 2011). The economic impact depends on the ability of a rural community to provide labor, supplies, and housing for the construction project. That responsibility lies partially in the state and education system. Texas has two large universities focusing on training and educating workers to build and maintain wind-related structures and infrastructure. On the large scale, wind infrastructure construction and maintenance provide over 73,000 jobs across the United States (AWEA 2016). 20,000 of which lie in factories building new wind energy infrastructure (AWEA 2016).

In addition to the increase in jobs, wind energy also benefits the local communities where wind farms are installed. These local communities receive monetary benefits in the forms of tax revenue and land leases for the wind farms constructed in their communities. The total statewide economic input for the wind installation in Texas is estimated to generate $1.8 billion in output over its 20-year life span. Local output was estimated at $730 million broken down to $0.52 million per MW of installed capacity (Slattery 2011).

The Department of Energy has released a statement titled “Wind Vision”, outlining its goals for the increase in wind energy production capacity out to the year 2050, with the goal of reaching 20% wind dependency by 2030 (Energy). Based on current trends, consumers would save $280 billion by 2050, assuming 20% dependency reached in 2030 (Energy). Additionally, the local communities would be receiving $3.2 billion annual in tax benefits and land lease payments for wind infrastructure (Energy). This long-term goal would revive the economy in local communities and save consumers money on utilities. Increasing our wind energy production would decrease the dependency on coal and natural gas, and the price fluctuations that accompany that dependence.

While the local revenue and saving for consumers show the benefits of increasing wind production capacity, along with that increase in production comes the increased maintenance cost for wind infrastructure. The national average for wind turbine O&M (Operations and Maintenance) is $48,000 per MW capacity (New Energy Update 2017). Based on the national capacity of 74,271 MW, the national O&M costs could reach $3.56 billion annually (GWEC 2015). This is large enough to be concerned about the long-term economic cost of wind turbines. While the production and construction companies will publish the added benefits to consumers, the costs of operating and maintaining the turbines are not widely known. In addition to the costs of O&M, wind turbines cost between $1.3 and $2.2 million per 1 MW of capacity to build (Windustry). Private investments totaled $114 billion from 2008 to 2015, or roughly $16.3 billion annually (GWEC 2015). While these private investments are currently high, we cannot disregard the climbing O&M costs of wind energy, and where that money will source from if the private investments dry up.

Environmental

One environmental benefit of wind energy is the reduction in water usage. Water shortage is one of the largest issues facing our country today and in the future. The main cause is simple: population increase. As the population of the United States increases, so does the demand for water. The unsettling fact is that there is no source for this increased demand.

Instead, the pressure is put on our already strained water sources. Conventional energy production methods use large amounts of water. Coal, natural gas, and nuclear plants all rely on water to power steam turbines. In addition to water for steam, nuclear plants require water for cooling the fuel rods. This cooling water is a critical component of the process and requires purification after use. Nuclear production uses 0.62 gallons of water per kilowatt hour produced, being the highest water consumer among energy sources. Comparably, coal uses 0.49 gal/kwh, and gas uses 0.25 gal/kwh (Saidur 2011). However, wind energy uses significantly less water. As no steam or cooling is required, the water usage is extremely low. Wind energy consumes 0.001 gallons of water per kwh of energy (Saidur 2011). This reduction in water consumption for energy production could relieve stress on the watersheds, and aid in the recharging of local aquifers.

In addition to the reduction of water usage, wind energy also helps decrease the driver of global climate change, greenhouse gasses. The cause of the reduction in greenhouse gasses is simple: wind energy does not require any burning of fossil fuels to create energy. Compared to conventional sources of energy production, wind energy reduces emissions by 0.33 to 0.59 tons of CO2 per kilowatt hour of energy produced (Saidur 2011). This reduction in greenhouse gas multiplied by the country's energy production could positively impact the current emissions of greenhouse gasses.

While the positive impacts are strong, there are also negative environmental impacts related to wind energy, the largest being avian deaths. The height of the turbines and varying speeds of the blades caused 150,000 birds to be struck and killed by wind turbines in 2009. To put that into perspective, the same year cats killed 1,000,000,000 birds (Saidur 2011). While this argument is important for some species that are at risk, it is largely an unimportant issue. The other quantitative impact is noise pollution. One environmental study reported that wind turbines operate at 9 dB above ambient noise levels (Saidur 2011). Noise is measured on a logarithmic scale, in increments of 3 dB. Each increment of 3 dB is an added 50% of pressure exposure (NetWell 2019). Therefore, an increase in 9 dB is a 150% increase in exposure pressure. While the levels of wind turbines fall below the recommended OSHA level for hearing damage, the noise is still audible.

The other large environmental impact is the visual impact of wind turbines. This is largely an aesthetic issue, and a matter of opinion. Wind farms are often located in vast open spaces, often near the coast or large mountain ranges. Unfortunately, these areas are often known and economically beneficial for their natural beauty. Some people are bothered by looking at wind turbines on the landscape, and some are not. This is an issue that will continue to be fought on both sides as long as wind farms are being constructed, and the "right" answer is up to the observer.

Ethical Issues

The ethical impacts of wind energy are more of qualitative behavior than quantitative. When considering environmental impacts, it is best to compare renewable energy to fossil fuels. While there are negative environmental impacts, these impacts are significantly smaller than similar impacts caused by fossil fuels. As stated above, wind energy produces less emissions and uses less water than traditional fuels. Since they use less, they could be considered as a better source for energy than traditional methods. The issue with renewable energy is that no type of renewable energy is 100% clean and causes no impact on the environment. The ethical dilemma is to what degree do we ignore these impacts, as they are likely to be less than the impacts caused by traditional fossil fuels. In regard to the economic impacts, this is a highly qualitative and speculative topic. It is true that investing in wind energy infrastructure will cost a significant amount of money, and the operating and maintenance costs will rise with an increase in number and size of wind farms. However, we need to decide when these costs are worth it in order to secure clean energy for the future.

Conclusion

We have an ethical responsibility to protect our planet and ensure its health. Directly tied to this responsibility is the human right to a clean and healthy environment to live in. We can set the example in our country by ensuring clean, renewable energy that limits the impacts on our planet. We need to critically think about the feasibility of our current practices, and how these can be remediated with technology that already exists today, such as wind energy. The economic and environmental impacts stated above show that there are positive and negative impacts of wind energy. However, we as a society need to decide if the negative impacts are worth ignoring or overcoming in order to support the positive effects. While we might need to spend some money to increase the current wind infrastructure in the United States, it will ensure clean energy for future generations. We need to think less about the direct costs and think about the ethical implications of continuing using fossil fuels as our primary source of energy production.

8f. Harnessing the Atom: The Ecological Debate of Nuclear Energy.

Tobin Brown

With the threat of climate change and the rise of ecological activism, energy producers have encountered pressure to limit and reduce its environmental footprint. This has manifested in a variety of ways including taxation, a call for a reduction of energy usage, and exploration of alternative forms of generation. Among them, and perhaps the most polarizing of alternative energy forms, is nuclear energy. However, the exact processes involved in the creation, fueling, function, and environmental impacts of a nuclear reactor are often misconstrued and misunderstood.

Nuclear reactors operate by harnessing the energy released from nuclear fission and using it to heat water into steam, which operates turbines much like conventional fossil fuel systems. The fission involves adding a neutron to an atom of a heavy element (usually Uranium 235 or Plutonium 239), which destabilizes it and causes the atom to fragment into several smaller atoms (Figure 8.4). This decay releases more neutrons, which can strike other atoms of the heavy isotope, and continue the process (Wilson 1996). Each split releases a small amount of energy, which when multiplied by the sheer number of atoms in a kilogram of fuel, is an immense amount.

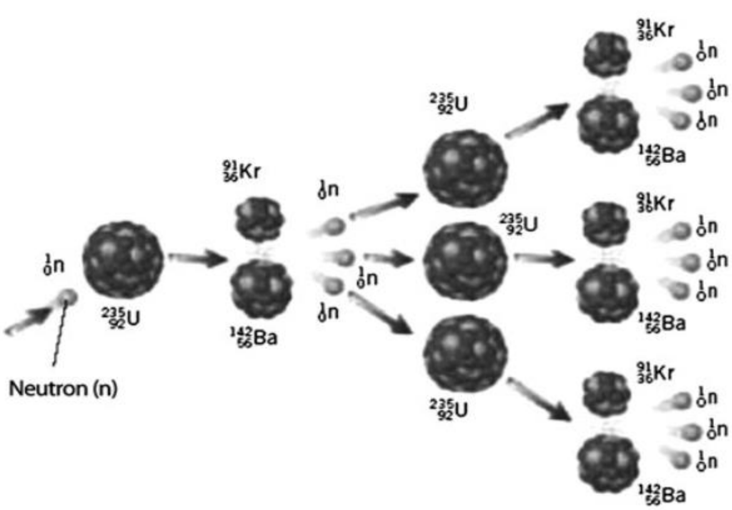


Figure 8.4. Model of the fission reaction of Uranium 235. (Cadenas. 2012.)

Concerns about nuclear energy's environmental footprint and its possible ecological impacts relative to other energy production methods raise the question of whether it is an ethically sound, safe, alternative energy source. CO2 emissions are one of the biggest inputs to climate change and are often held up as a standard of green infrastructure. Nuclear reactors produce almost no CO2 from their operation, but their construction and supply does. Even conservative estimates show nuclear to have a far lower emissions rate per unit energy produced than most other forms of energy (Figure 8.5). However small these emissions are, they are not localized to the country of operation, and much of the impact occurs in other regions (Zafrilla et al. 2014). Is it acceptable to pawn emissions off on other countries? This disconnect between emissions complicates enforcement of greenhouse gas limits and reduces accountability, allowing for a facade of compliance and a skewed burden on the supplying countries.

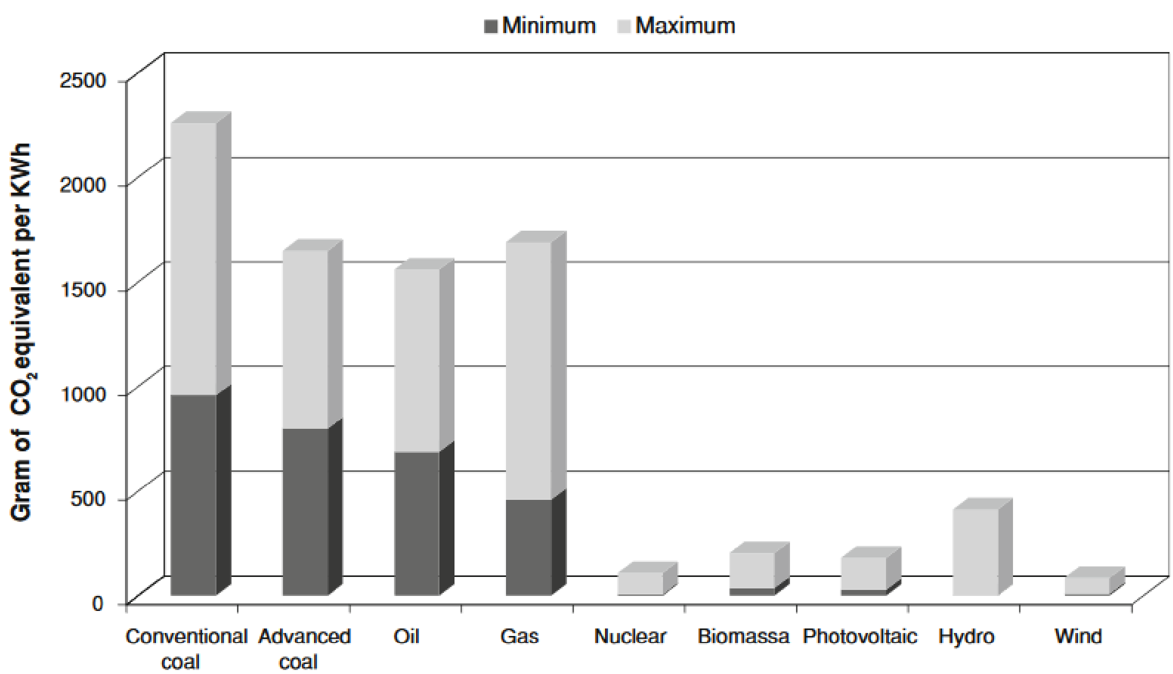


Figure 8.5. Comparison of CO2 emissions among energy production sources. (Boyle 2003)

The current standard nuclear facility will have a lifetime carbon emissions footprint between 16.19 and 37.75 gCO2e/kWh (Zafrilla et al. 2014). This encompasses the construction, mining and refinement, transport, operation, waste, and decommissioning of the facility and fuels. Emissions are not the only aspect of their footprint. Energy production is commonly measured in Megawatt hours, which is an amount of energy used or produced at a constant rate for a set amount of time. A machine that consumes 1 Megawatt of energy that runs for 1 hour will use 1 Megawatt hour (MWh) of power. An average nuclear facility will produce 7,500,000 MWh from 24 tons of enriched Uranium fuel in a year, and each ton of fuel will use roughly 387 m^2 of land, and $7.46*10^6$ Liters of water, which comes out to ~154 L per MWh of water and 0.008 m^2 per MWh of land use (Schneider et al. 2013). Over the operational lifetime of 30-40 years, this adds up, especially considering that we are already using far more land and water than is sustainable (Hoekstra et al. 2014).

While the conventional environmental concerns are relevant, nuclear energy has another, far more unique aspect that needs to be considered. Radiation has been a fearful word since the 1940's and is an unavoidable nuclear power generation, but there are many misconceptions. Nuclear reactors produce less radiation than coal power plants, both of which are insignificant compared to the background radiation experienced in everyday life (Figure 8.6). A nuclear plant releases 0.2 Micro-Sieverts of radiation a year, which is a tiny fraction of the radiation we receive from medical visits or even trace radiation in the food we eat.

However, the historical potential for disaster of a nuclear power plant is worth thinking about, namely the accidents; Chernobyl, 3-Mile Island, Kyshtym, and Fukushima (Xiang and Zhu 2011). These were terrible disasters, but they were entirely due to human error, mostly engineering oversights or fraudulent or missing safety systems. These could have been avoided, but lack of knowledge and a lack of oversight allowed the systems to fail. Until we can have a stringent worldwide set of regulations that will be strictly enforced, this could happen again. Since worldwide cooperation is unlikely, and people always find ways to cheat things, the possibility of disaster remains, and must be considered in a decision to utilize nuclear reactors.

In addition to these impacts, the spent, radioactive fuel rods need a stable, long-term storage location (US DOE, 2014). The spent fuel rods are radioactive enough to be damaging to biological life and often require decades or even centuries to reach safe levels. The most viable method is to allow the material to cool down and lose some radioactivity for several years in water storage, often near the reactor site. They are then sealed in casks and stored underground indefinitely, either deep in a geologically stable area, or just a few meters below the surface in a specially built bunker. There are solutions for this, like the proposed Yucca Mountain repository in Nevada or various deep mine shaft storage sites in Europe (WNA, 2013).

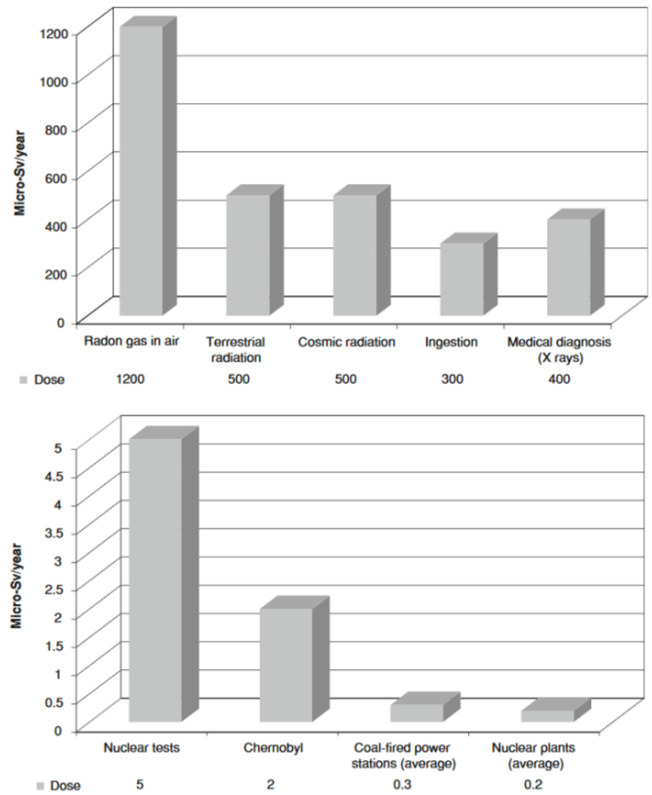


Figure 8.6. Radiation received by the public. (Cadenas 2012)

Nuclear power is extremely competitive in terms of greenhouse gas emissions and does not share many of the shortcomings of other energy sources, but it does have a major shortcoming. A nuclear reactor will use more water per unit energy than any similar coal or gas plant, with most of the use in mining and refinement (Figure 8.7). Our current water use habits are unsustainable, a trend that is likely to continue with population growth and the expansion of developing countries, and anything that would increase the demand on our water supply is ill-advised (Hoekstra et al. 2014). While nuclear power plants do not require freshwater, they are not always able to be on a coast, especially in landlocked or large countries, and the uranium mines are almost never coastal. A widespread adoption of nuclear power would likely lead to significantly increased water usage, and with water poised to become one of our most precious natural resources, this should not be undertaken lightly.

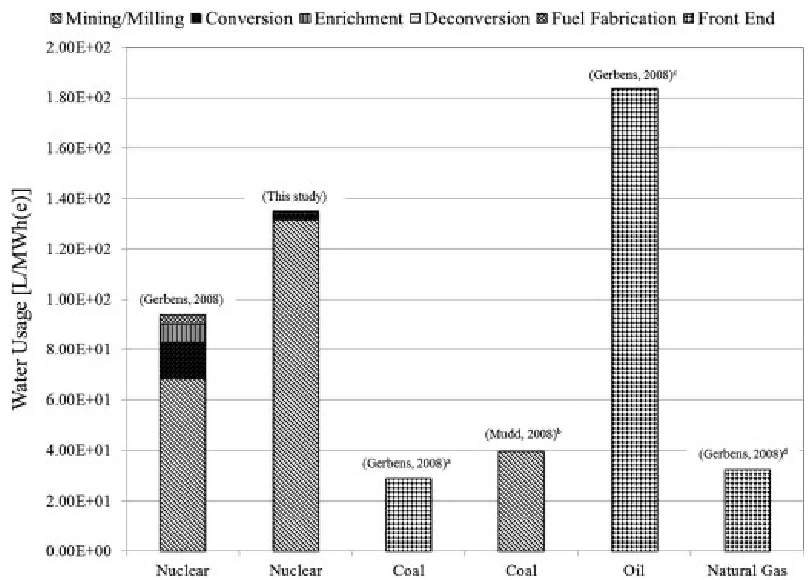


Figure 8.7. Water use per unit energy for several energy production methods. (Schneider et al. 2013)

Nuclear energy is a huge risk/reward debate. On one hand, it can provide a constant and immense supply energy without the gaps and inconsistencies of solar and wind and a fraction of the carbon emissions of almost any other production method. On the other hand, it requires large amounts of water, and supports the mining, transport, and long-term storage of hazardous and radioactive materials, the potential exploitation of developing countries, and has the potential for far-reaching catastrophic accidents. These questions are hard to answer, and while nuclear energy could help solve our carbon emissions problem, the negative effects could be felt by millions. With such a widespread area of effect, and worldwide implications, who should make these decisions?

8g. Nuclear Power Plant Accidents, Safety, and Media Coverage

Ross Hurlbert

Introduction

After the 1986 nuclear meltdown at the Chernobyl nuclear power plant in Ukraine, news corporations in the Western world went on a reporting frenzy. Absurd headlines such as “2,000 DEAD IN ATOM HORROR” from the *Daily Mail*, to reports claiming “many hundreds dead” (*Daily Mirror*) to even 20,000 dead (*New York Post*) drilled fear into Western societies. The truth of the matter, according to a 2008 report from the United Nations Scientific Committee on the Effects of Atomic Radiation, was that the immediate death toll from the accident was 54 people.

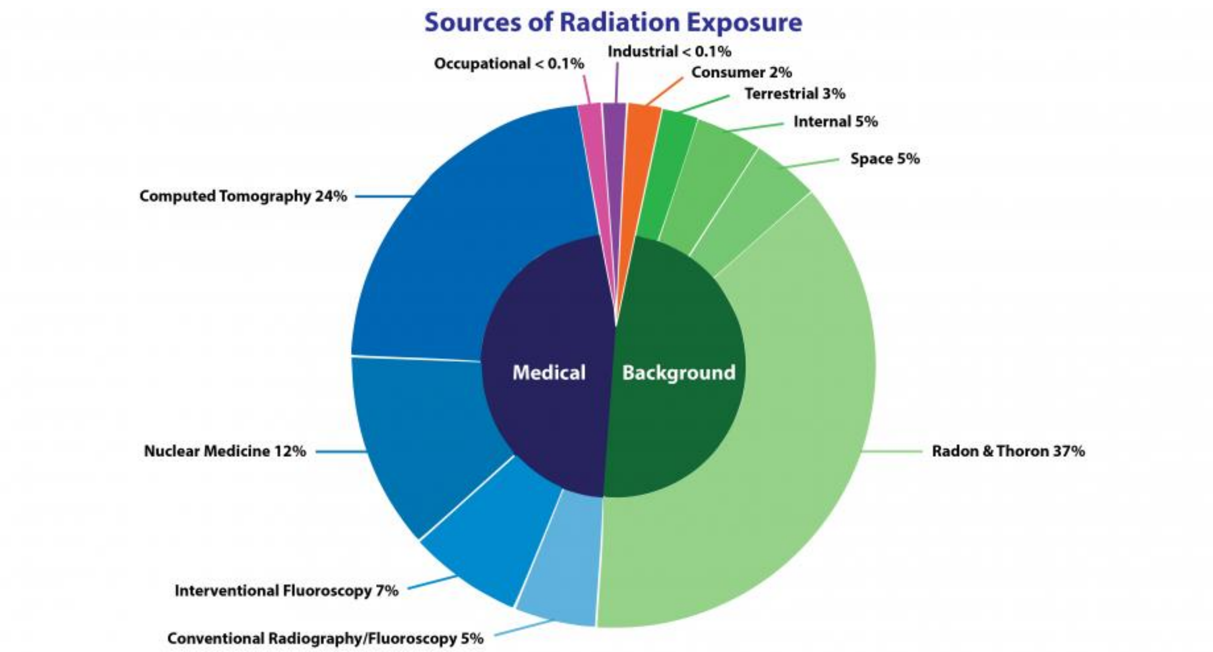
Media coverage of nuclear power plant accidents shapes the way society views this energy source. The future of nuclear energy largely depends on government subsidies and support from the public. The fear-instilling headlines, ill-informed journalism and overly simplistic reports on accidents are problematic for the future development of nuclear energy, an increasingly important energy pathway in the wake of anthropogenic climate change.

Background

Radiation

Radiation is the emission of energy from atoms in the form of particles or waves. The nucleus of an atom carries a positive electrical charge, while the electrons carry a negative electrical charge. These forces within the atom work toward a strong, stable balance by getting rid of excess atomic energy. In that process, unstable nuclei may emit a quantity of energy known as radiation. While there are multiple forms of radiation, the most important form for safety concern is ionizing radiation. Ionizing has enough energy to alter molecular bonds and strip electrons off the materials that it passes through. The main concern for ionizing radiation lies in its effects on living cells when it is passed through them. These effects range from no cellular damage to complete cell death. When reproductive cells are exposed to ionizing radiation, it may induce DNA damage which can be passed on to offspring, potentially resulting in birth defects or increased likelihoods of cancer (Hore-Lacy 2012).

Radiation is an inherent part of nature. There is no such thing as a radiation-free environment in the natural world. Natural radioactive material exists in the earth, in all food and water, in the air, and even our own bodies (Waltar 1995). Figure 8.8 shows the sources and average of radiation exposed to the average United States citizen annually (Schauer 2009). When accidents occur and release radiation into the environment, the question is not whether there is radiation present (there always is), but how much and whether that level is harmful.



Average Annual Radiation Dose

Sources	Radon & Thoron	Computed Tomography	Nuclear Medicine	Interventional Fluoroscopy	Space	Conventional Radiography/ Fluoroscopy	Internal	Terrestrial	Consumer	Occupational	Industrial
Units mrem (United States) mSv (International)	228 mrem 2.28 mSv	147 mrem 1.47 mSv	77 mrem 0.77 mSv	43 mrem 0.43 mSv	33 mrem 0.33 mSv	33 mrem 0.33mSv	29 mrem 0.29 mSv	21 mrem 0.21 mSv	13 mrem 0.13 mSv	0.5 mrem 0.005 mSv	0.3 mrem 0.003 mSv

(Source: National Council on Radiation Protection & Measurements, Report No. 160)

Figure 8.8 – A United States citizen's annual average radiation exposure, according to the National Council on Radiation Protection & Measurements (Schauer 2009).

Reactor Core Meltdowns

The potential of nuclear power plants to "meltdown" and send extremely harmful doses of radioactive particles into the environment is the main concern of nuclear accidents. The term 'meltdown' refers to large amounts of heat within a reactor to the point of the reactor being damaged by the heat it produces itself. There are varying degrees of nuclear meltdown. A partial nuclear meltdown means that fuel rods have been damaged but the process of cooling the system was carried out before the reactor reached total meltdown. Total meltdown means cooling power is lost within the reactor and excess heat causes the radioactive fuel rod contents to sink to the bottom of the reactor and melt through its containment vessel (Hore-Lacy 2012).

Accidents

Chernobyl Unit-4 (1986)

In 1986, Chernobyl was one of four nuclear power stations operating in the Ukraine. Chernobyl had four reactors in operation with Units 5 and 6 being built at the time of the accident. The reactor design in-place at Chernobyl was one of two types of reactors built in the 1970s by the Soviet Union. These RBMK-1000 reactors had fundamentally flawed designs and poor safety measures that made them more dangerous than those designed in the West.

To begin, these RBMK reactors had no radioactive containment system built within the structure of the building (Hore-Lacy 2012). This lack of containment is considered by many to be the most critical design flaw, because in the event of a reactor core meltdown, radioactive nuclei should still be contained as they are in reactors designed in the West. Soviet RBMK-1000 reactors were graphite moderated; this means that graphite is responsible for slowing down neutrons that are released during the fission of U-235. The use of graphite as the neutron moderator poses a vital problem to the design of the RMBK reactor; when graphite is used as the moderator, the sudden loss of cooling water within the reactor core does not stop the nuclear chain reaction (Medvedev 1990). RBMK-1000 reactors had a positive void coefficient, meaning that a loss of cooling water within the reactor core results in a temperature rise and increase in power output. This unfortunately causes more coolant water to turn to steam, potentially leading to an uncontrollable climb in reactor power output (Smith and Beresford 2005). This design is dangerous and most reactors in the world have a negative void coefficient.

The accident at Chernobyl occurred during an experiment to test the function of an electrical system in the event of a main power supply failure. To conduct the experiment, reactor power output was reduced to 25% of its maximum power output (700-1,000 MW), however, power output unexpectedly dropped to only 30 MW. Operators then removed some of the control rods (which helped stabilize reactor power to 200 MW) and varied the flow rate of water. This measure accidentally caused a temperature variation in the cooling circuit resulting in an automatic printout that told reactor operators to shut down the reactor immediately. They ignored this warning and continued the experiment. Reactor power then began to increase exponentially and the production of steam led the reactor to explode. Since there was not an adequate containment structure in place, radioactive isotopes began to pour out of the reactor, contaminating the area surrounding the plant. (Smith and Beresford 2005).

Chernobyl Media Coverage

Media coverage at Chernobyl was interesting considering that the Soviet Union at the time had a state-controlled press, and it wasn't until 10 days after the accident when the first extensive Soviet public report appeared (Friedman 2011). An analysis of media coverage in the United States during the first two weeks of accident coverage found that 46 percent of the 394 articles and 60 percent of the 43 newscasts included some radiation information. Information about radiation levels was infrequent and unspecific, leaving the public without proper knowledge of the risks of exposure. The most common explanation was to say that the levels were high, moderate, or low without giving the reader actual quantitative data. Another common method used to convey information about radioactivity was to use the same high-moderate-low approach and combine it with a comparative radiation level (Friedman 1987). To add to the vagueness of media coverage, limited effort was made by media corporations to explain radiation, and few illustrations, graphics, or glossaries of radiation terms appeared in the newspapers. Television coverage frequently included graphics, but these were mostly maps showing the spread of a radioactive cloud and a simplistic illustration of a nuclear reactor burning or in the process of a meltdown. More than 80 percent of the articles and 93 percent of the newscasts included general risk estimates for American citizens; most said there was little or no risk (Friedman 2011).

Fukushima (2011)

Construction of Tokyo Electric Power Company's (TEPCO) Fukushima Daiichi nuclear power plant in Japan began on July 25, 1967 and was commissioned on March 26, 1971. This plant consisted of six reactors that powered electrical generators with a combined power output of 4.7 GWe, making this complex the 15th largest nuclear facility in the world (Eisler 2013). On March 11, 2011 Japan was shook with a magnitude 9 earthquake, which sent the three operating reactors into an automatic shutdown. The earthquake was followed by a massive tsunami; disabling portions of Daiichi nuclear power plant.

The nuclear reactor type at Fukushima was boiling water reactors (BWRs). Boiling water reactors are a type of light-water reactor (LWR) that uses reactor heat to generate steam through heating water, which then generates electricity by driving a steam turbine. Since the plant had a loss of power, back-up diesel generators were automatically turned on to maintain power in order to cool the reactor. This is usually a great safety measure; however, the generators were flooded by the tsunami because they were housed in the basement of the reactor building. The diesel generators failed an hour after they started generating electricity (Hore-Lacy 2012). To make matters worse, Units 1-4's low and high voltage switchboards (responsible for powering nearly all reactor equipment) were submerged and lost their ability to function. The power blackout resulted in a loss of coolant to the three reactors that had been operating at the time. Since the reactors had only recently been shut down due to the earthquake, decay heat within these reactors remained trapped with nowhere to go. This excessive heat caused the core containment vessel to melt and the steam within reacted with the zirconium fuel rod outer covering to produce hydrogen gas. As response workers attempted to vent this gas, it collected in the top floors of units 1, 3, and 4. Hydrogen gas in these buildings created explosions which spread radioactive materials that had melted through the reactor pressure vessel into the atmosphere (Hore-Lacy 2012). The main radionuclide released were iodine-131 and caesium-137. More than 200,000 people living within a 20km radius of the site were evacuated (Eisler 2013).

Fukushima Media Coverage

Since the Fukushima nuclear plant accident took place during the age of the internet, people worldwide were gathering information on the event through many media. Prior to the nuclear accident, media coverage revolved around the earthquake and tsunami that had taken place in Japan. At this time, BBC also reported the condition of some nuclear plants sited within the earthquake zone. BBC quoted the cabinet secretary minister, Yukio Edano, who stated that the Fukushima plant had stopped automatically and was in safe condition. The NHK news channel in Japan started cancelling programs on sports and game shows to become a constant news broadcast channel and directed its focus on the tsunami and earthquake events of the country (Imtihani and Mariko 2013).

The situation in Japan shifted drastically when Yukio Edano later held a press conference and informed the public that the reactor cooling process had not gone as planned, but no radiation leaks had been detected. The Japanese government then declared a state of nuclear emergency. At this time, the BBC seized the opportunity and began to focus more on the nuclear accident at Fukushima, while the NHK continued its reporting primarily focused on the handling of the natural disaster (Imtihani and Mariko 2013). As days went by and the events at Fukushima unraveled, motives of the NHK and BBC became clearer. NHK's selection of information seemed to favor intel sourced from the Japanese government and TEPCO. The NHK seemed to be motivated by reducing the Japanese public's anxiety on the events that were unfolding, even to the point of trying to hide things such as the hydrogen gas explosions that released radioactive nuclei into the atmosphere. The BBC, on the other hand, was generally more critical of the Japanese cleanup methods and more skeptical about the information given by the government and TEPCO (Imtihani and Mariko 2013).

Media coverage during and after this accident was extremely variable in the amount of bias at which it was presented to various publics worldwide. It is amazing how the reporting tones shift from country to country based upon cultural attitudes on nuclear energy. A study comparing media coverage of the Fukushima accident demonstrates interesting reporting differences between Germany, France, Switzerland, and the UK (Kepplinger and Lemke 2016). The newspapers in Germany and Switzerland gave the nuclear disaster at Fukushima more coverage than the French and UK papers. In all countries, newspapers did little reporting about the specific causes of the reactor accidents. Kepplinger and Lemke also investigated the effects that editorial lines had on domestic nuclear coverage. They concluded that, "the more negatively journalists evaluated nuclear energy in editorials and commentaries, the greater the extent to which domestic nuclear energy was included in the entire coverage of Fukushima and its consequences" (Kepplinger and Lemke 2016). The tone used in the papers' editorial lines also had a large influence on which experts were consulted for their opinions. Articles with positive views on nuclear energy predominantly used expert opinions that gave statements that shined positive light on nuclear energy, while articles with negative views on nuclear energy did just the opposite (Kepplinger and Lemke 2016).

Media, Science, and the Public

Disasters are infrequent occurrences that attract public attention; this makes them prime news material to be sold by mass media to the public (Imtihani and Mariko 2013). One must be conscious of the medias ability to capitalize on such events to capture our attention. Anyone who stays current on the news cycle knows how negative stories get the spotlight over positive ones. In the case of the nuclear energy sector, you rarely ever hear positive news about the industry. This inevitably gives the general public an unbalanced perspective of nuclear energy. Furthermore, as we have seen in international reporting on the Fukushima disaster, it is vital to recognize the cultural and political biases of where your information is sourced from. Reporters, journalists, and editors can filter which facts, quotes, and general information gets presented to the public; this allows media to frame their coverage of events as they see fit. Knowledge and awareness of media framing is key to seeing through such biases. Different interpretive framings of nuclear energy were discussed in *Nuclear Disaster at Fukushima Daiichi* (Hindmarsh 2013). These include the pro-nuclear frames of *progress*, *energy independence,* the *devil's bargain*, and the anti-nuclear frames of *soft paths, public accountability,* and *not cost-effective*. The *progress* frame entails nuclear fission as holding immense potential for either good (energy production) or evil (weapons of mass destruction). The *energy independence* frame was used heavily during the 1970s oil crisis, and emphasizes less dependency on other energy sources. *Soft paths* entail a critique of nuclear power as insensitive to its ecological consequences, the *public accountability* frame relates to anticorporate narratives, while the *not cost-effective* frame questions the economic surrounding nuclear energy. Lastly, the *devil's bargain* frame deals with catastrophic trade-offs, this is a mixture of pro- and anti-nuclear tones that is often used to justify the low-carbon emission reality of nuclear energy in the face of a greater threat to humanity (e.g. climate change) (Hindmarsh 2013).

The importance of an objective approach to media consumption cannot be stressed enough. In our two-party system, one must be aware of their own personal political leanings in order to objectively consume information sourced from mass media. Too many people only get their information from sources that they agree with rather than attempting to step back and objectively analyze the topic at hand. Influential media companies in our free market system rely on profit and have the ability to mold the public's opinions in the direction they deem fit. Scientific knowledge is always refining itself. Participants within this realm are held much more accountable for their methods and conclusions than media corporations are for their claims.

Granted that the general public has limited knowledge of chemistry and physics, the type of simplistic media coverage seen during and after Chernobyl detrimental towards the goal of reaching the truth. There is an underlying issue regarding the complexity of nuclear energy and its accidents; the public wants quick information, not a nuclear physics lecture. Along with this point, I don't think the general public cares to understand the technicality of what is going on. They too frequently will believe the headlines and snippets that produce an impactful emotional response within them. A revolution of public interest in scientifically informed discussion is an effective way to combat issues stemming from simplistic reporting. Giving a nuclear energy expert less than a minute on a news panel is not enough time to dissect such technical information for the general public.

A massive concern for discovering the truth surrounding nuclear accidents lies not only in media framing, but in nuclear energy corporations and governments attempting to make information either deceptively slated or even inaccessible. This problem was a major concern during the Fukushima accident because news corporations had to rely heavily upon information granted to them from the Japanese government and TEPCO.

Safety: Going Forward

Nuclear reactor safety is constantly being improved and accidents are necessary in order to make this energy source safer for its use by future generations. One could make an argument that accidents in the past have proven how safe nuclear energy is relative to coal, petroleum, and hydro-electric energy sources. Many questions about reactor safety arise when learning about the accidents that occurred at Chernobyl and Fukushima. Accidents expose important reactor design flaws. In the case of the RBMK-1000 reactor, the Chernobyl accident exposed key flaws in the building's containment structure, the moderator used within the reactor, and issues concerning reactors with a positive void coefficient. If the Soviet RBMK reactors had been designed with a containment structure over the reactor building (like those in the West) could such a catastrophe have been avoided? An even broader applicable question is; would this catastrophe have even occurred if the Soviet Union had used reactors that were up to the Western world's standards?

Fukushima exposed the need for nuclear power plants to have coolant delivery systems that can be carried out even in the event of total power loss. The fact that the backup diesel generators were housed in the basement of the turbine building and switchboards on the first floor and basement seems rash given Japan's history of tsunami events that cause massive flooding events. One can plainly see how much of a problem submerged electronics poses to proper nuclear reactor functioning.

Another question that comes to mind is; where should/shouldn't we build nuclear reactors? Building near or on tectonic plate lines is a huge safety concern, but who is to tell a country with frequent seismic activity (e.g. Japan and China) that they cannot harness the atom for their own energy security? Furthermore, building a reactor on the coast at near sea-level is a recipe for disaster, especially in countries known for flooding events and tsunamis.

Since most nuclear accidents occur due to the loss of coolant to the reactor core, passive measures must be implemented in the future to ensure the safety of humans and the environment in the event of a power outage. Traditionally reactors have relied on active systems to power electronically driven pumps and valves to maintain proper temperatures and coolant levels. A new reactor type in the United States, the AP1000, uses large water tanks housed above the reactor and pools of spent fuel (Eisler 2013). This is a great safety measure that should be adopted by nuclear reactors worldwide because in the event of power loss coolant can still be delivered to the core by gravity rather than electronically driven pumps.

Conclusion/Looking Forward

The events that unfolded at Chernobyl and Fukushima demonstrate the importance of reactor safety improvements for the future. Reactor design is always becoming safer, but the element of human error can never be eliminated. The importance of an objective approach to media consumption cannot be stressed enough. With information presented to you (especially from media corporations) it is extremely important to be a reasonably skeptical individual in order to seek out the truth. The cross-checking of sources is important when dealing with any new information, especially information about the nuclear industry due to simplistic journalism and framing biases.

8h. The East vs West: Economics, Culture, and Ethics of Energy

Michael Sainsbury

Renewable energy is of critical importance to the future of the United States as well as all other nations, for it not only will affect the physical climate of Earth, but the economic climate as well. The domestication of animals, the revolution of combustion, and the harnessing of fission have all been transitional times for mankind in how energy is both produced and distributed. In an ever-globalizing market, the next transition in how energy is produced will be in tune with international economic actors. In this paper, the United States and China will be looked at for their hallmark spending on energy production as well as how those energy pursuits are affecting countries markets, populaces, and standards of living. Influences on the energy market from private companies, governments, and public spending will be accounted for in each country's analysis. It is important to understand that there are many factors contributing to the relationships between Earth's ecosystems and the type of energy we invest into and rely upon.

China has more solar output than any other country on Earth; China is also the world's leader in production and sales of photovoltaics (Biello 2008). While those two statistics together make sense, the most impressive feat from the communist regime has been to be the first country to pass 100 Gigawatts of annual solar generated electricity, accomplished in 2017. China's biggest energy company, Trina Solar, has shipped over 40 GW worth of solar panels worldwide as of 2018 (Trina Solar… 2019), and has been in business since 1997. Trina Solar is one of dozens of relatively new companies to take advantage of the social yearn and governmental push for clean energy independence. Since the 1990s, the Chinese government has unveiled over 100 policies supporting the photovoltaic industry (Gabbatiss 2019). Government legislation and economic influence like this has led to a sharp decrease in the cost of solar power in the nation, making solar power even cheaper than grid power in most regions. In a recent study, many of China's major cities were analyzed, and every single one could have solar projects conducted without government subsidy for a cheaper price than sustained grid electricity (Gabbatiss 2019). These truths aren't even the beginning of astonishing when compared to looking at China's long-term clean energy goals: "studies reveal that China should be able to reach 26% renewable energy by 2030 and 60% renewable energy and 86% renewable electricity by 2050," (Yang et al. 2016). The bright future for China's solar industry may sound imperfect at first, but every dramatic shift in energy has a cost. Environmental factors such as increasing soil and water temperatures (Wu et al. 2014), increasing bird mortality in the vicinity of solar infrastructure (Hernandez et al. 2013) (along with other ecological impacts), and of course the mining required to support solar production (Mulvaney 2014, Cha 2008). Unethical practices such as dumping waste in villages too poor to legally or physically defend themselves has continued in the case of solar factories and mining efforts. The cost benefit of profit margin and rapid expansion in an increasingly competitive solar market, environmental and human health standards are unfortunately taking a back-seat priority. If environmental protection technology is used, the cost to produce just one ton is around $84,500, while Chinese companies are making it at $21,000 to $56,000 a ton (Cha 2008). While private factories are producing critical materials to support the country's efforts to provide clean energy to itself, the contemporary cost of this rapid industrialization is human health. Theoretically, companies should collect all of their solar cell polysilicon waste products, process it, then recycle it. Smaller solar companies don't have the technology to recycle, and now are just releasing it directly into the air (Cha 2008).

It is dangerous to assume a motive behind solar power, as there are many perspectives with overlapping goals. Profit, sustainability, and image are just a few motives that drive the Chinese government and private sector to pursue solar energy, but at what cost? Is another promise of a better tomorrow worth toxic air today? Those impacted by solar industrialization in China may disagree with experts shielded from the reality of progress. The growing pains of solar are already paying off, increasingly making fossil fuels less cost-effective (Yang et al. 2016). In, arguably, predictable Chinese culture, individuals experiencing devastating effects by the solar industry are a small price for long-term clean energy prosperity.

While China is investing heavily into solar, the United States is optimizing its natural gas industry, particularly in the realm of massive hydraulic fracking, or 'fracking' for short. The United States produced more natural gas and petroleum than any other nation. The National Petroleum Council estimates that hydraulic fracturing will eventually account for more than 70% of natural gas development in North America. As of 2016, fracking makes up about two-thirds of all U.S. natural gas production, according to the Energy Information Administration (Cook & Perrin 2016). Fracking has cultural stigma due to the nature of the process causing geologic disturbance along with the potential for contamination due to the use of fracking fluid. Fracking fluid is composed primarily of water and sand, with approximately 1% are various chemicals used to lubricate fracking operations, according to the Environmental Protection Agency (EPA).

The fracking industry has been very careful thus far to avoid any type of mass contamination of clean water, and in fact most fracking fluid is pumped back out to be disposed of. Much of the fracking process varies with regulation. Fracking regulation is highly dependent upon several factors: state regulation, federal regulation, private sector demand, and political climate. States with a larger percentage of self-indicated Democrats are more likely to adopt environmental mitigation policies linked to fracking operations while states with a larger percentage of self-indicated conservatives are less likely to adopt the same policies (Davis 2017). Local culture and opinion play as much of a role in fracking success as legislation does, as in the U.S., the two are tightly linked. Much of what shapes opinion of fracking is how local economies are affected; communities that are given jobs may be more likely to appreciate the industry, but at the same time there are far too many stories of fracking ruining small business and upsetting locals. "Between the years 2007 and 2012, jobs in and surrounding the oil and natural gas industries have dramatically increased: a total of about 90,000 jobs in natural gas drilling, 193,000 jobs in extraction/mining, and 286,000 support jobs," (Cook and Perrin 2016). During the ~2007-2009 economic recession, natural gas production continued to rise, about 25% during 2007-2012. The economic powerhouse that natural gas production has become in the United States is not falling short even today, with the current political administration repealing several restrictive laws and regulations on natural gas. The amount of natural gas released from Earth has tripled to 15 Bcf/d (Billion cubic feet per day) in the United States from 2006 to 2018. The official statistics for 2019 natural gas production have not been released yet. The contribution of human-caused climate change is being continued by the practice of fracking, but compared to the case of China's solar industry, effects are more obvious and understood. While fracking is known to be bad, there is little cultural cover-up to make it seem something it is not.

These two countries are interesting ethical case studies in that they have pursued divergent routes to each other with regards to how they meet their energy demands of this 21st century. China's government has chosen solar power as a primary mode of production, and in doing so has rapidly revolutionized its technological and industrial capabilities. With legislative assistance and protection, companies related to solar infrastructure production are outcompeting other forms of energy harnessing. However, China has arguably chosen solar at an ethically expensive cost. The millions of Chinese exposed to illegally dumped solar waste as well as those working in horrible mining conditions to meet solar demands likely have a different opinion on how clean solar energy truly is. China may be collecting energy from the sun, but only by expending the wellbeing of millions of innocent people and the environment they inhabit. The United States is pursuing an energy plan opposite of China in almost every ethical way. We are refusing to *directly* put anyone in harm's way at the cost of clean energy goals. The U.S. instead continues to develop fossil fuel use in ‘clean’ and ‘responsible’ ways to minimize the impact of fossil fuels, while slowly flirting with ideas of introducing a diverse array of renewable energy sources. This while citizens are not directly impacted, they are *indirectly* impacted by most notably the effects of climate change. This is a cultural difference between China and the U.S.: the appearance of trading lives for results. While China won’t hide the fact of pollution in its borders and the health risks to its citizens, the U.S. won’t allow such risks, at least if they’re easy to see. Fracking has tripled the amount of natural gas released into the atmosphere since 2000, created potential for massive unnatural earthquakes, and contaminated clean drinking water. Both countries are saving face in opposite ways, and it works. China appears to be the king of clean energy, and the U.S. appears to have polished, safe energy. Neither are sustainable, and a balance must be met to meet energy future energy goals without putting millions at risk.

9. Ethical Issues Associated with Water Availability

9a. Ethical Consideration for an Inevitable Water Issue: Recognizing Surface and Groundwater as One Source

Chelsey Trevino

Groundwater-Surface Water Interactions

Groundwater and surface water share dynamic interactions and the water that they yield depend on zones of saturation connected between them which are understudied within the Gallatin Valley. Groundwater is a freshwater resource contained at various depths below the surface of the ground. Surface water is any freshwater resources on the surface of the ground such as, water flowing freely in streams, snowmelt, precipitation, and water stored within reservoirs. These two forms of freshwater resources interact, and the water yield depends on zones of saturation between surface water and the groundwater table below them. For example, when a stream's water surface is higher in elevation than the water table below it, the stream will lose water as it infiltrates to recharge groundwater through zones of saturation that connect streams and groundwater (Cantor et al. 2018). In contrast, if the stream's water surface is lower in elevation than the below water table, water will be lost from groundwater up through zones of saturation and released into the stream above. The complex relationship between groundwater and stream water use leaves many questions about future water availability within the Gallatin Valley. Understanding these interactions can help create monitoring projects that may result in future management plans recognizing surface and groundwater as one freshwater resource.

Gallatin Valley: Water Rights

Water rights can be a competitive market and will become increasingly significant for the Gallatin Valley as it grows. All water within Montana is owned by the state, and rights to use that water may be obtained via a water right permit. Montana utilizes the water right of prior appropriation, which is "first in time, first in right". This means that senior surface water right holders will have a right to their full water use while junior surface water right holders may experience regulation of use in times of water scarcity (Water Rights in Montana Handbook 2014). Gallatin Valley is located within Gallatin County and relies on water from within the Upper Missouri River Basin. The Greater Gallatin Valley sits within a closed basin - meaning all surface water coming into the valley has been completely allocated and increased surface water use cannot be permitted in order to maintain stream flows for downriver use. Halts on surface water right appropriations leave groundwater use as the only form of water for new development in the Gallatin Valley.

Groundwater appropriation comes in two forms: permitted groundwater wells and exempt groundwater wells. Wells exempt from the permitting process may be utilized for development intending on water use that is no greater than 10 acre-feet of water per year at a flow of 35 gallons per minute. Stream depletion zones are areas where hydrologic modeling concludes that stream depletion of 30% will take place after 30 days of continuous pumping from a groundwater well. An exempt groundwater well within a stream depletion zone restricts groundwater use to a volume of 2 acre-feet per year at a flow of 20 gallons per minute. If groundwater use for new development is expected to exceed 10 acre-feet of water per year at a flow of 35 gallons per minute, then a hydrologic report must be completed to determine if the proposed well could result in surface water net depletion. If the report concludes zero net depletion of surface water for the proposed location of the well, an application for a permit can be submitted to the Department of Natural Resources and Conservation for well development approval (Water Rights in Montana Handbook 2014).

It is very difficult for regulation and monitoring on groundwater use to take place for every well that is drilled, even those that are required to have permits. Exempt wells pose a risk of cumulative net depletion without the requirement of completing a hydrologic report before drilling the well. As the Gallatin Valley grows and current climate conditions continue to change snowmelt start times and duration, groundwater depletion could have a large impact on the community's valuable freshwater resource.

Implications of Increased Development on Water Availability

Gallatin County has over 18,000 currently drilled groundwater wells with an abundance of these wells located within the growing area of the Greater Gallatin Valley (Figure 9.1; Montana Groundwater Information Center 2019). Groundwater Information Center 2019). With so many wells in existence and an increasing demand for future groundwater use, important groundwater recharge areas should be considered to ensure no net depletion is taking place. Groundwater recharge takes place when excess surface water infiltrates through zones of saturation within the soil to penetrate through to groundwater reservoirs.

The Gallatin Valley strongly relies on groundwater recharge via additional water inputted by seepage from irrigation canals and irrigation of farmlands. The Montana Bureau of Mines and Geology completed a study highlighting the relationship between irrigation ditch water loss and groundwater recharge at various study sites throughout Montana. A study site located in Belgrade, MT lost approximately 250 million gallons of water per year per mile (Metesh 2011). Between 2007 and 2012 there was a reduction in farmland of 74,155 acres within the Upper Missouri River Basin and it is proposed that this is a result of an economic transition from agricultural-based to amenity-based (Niemi 2017).

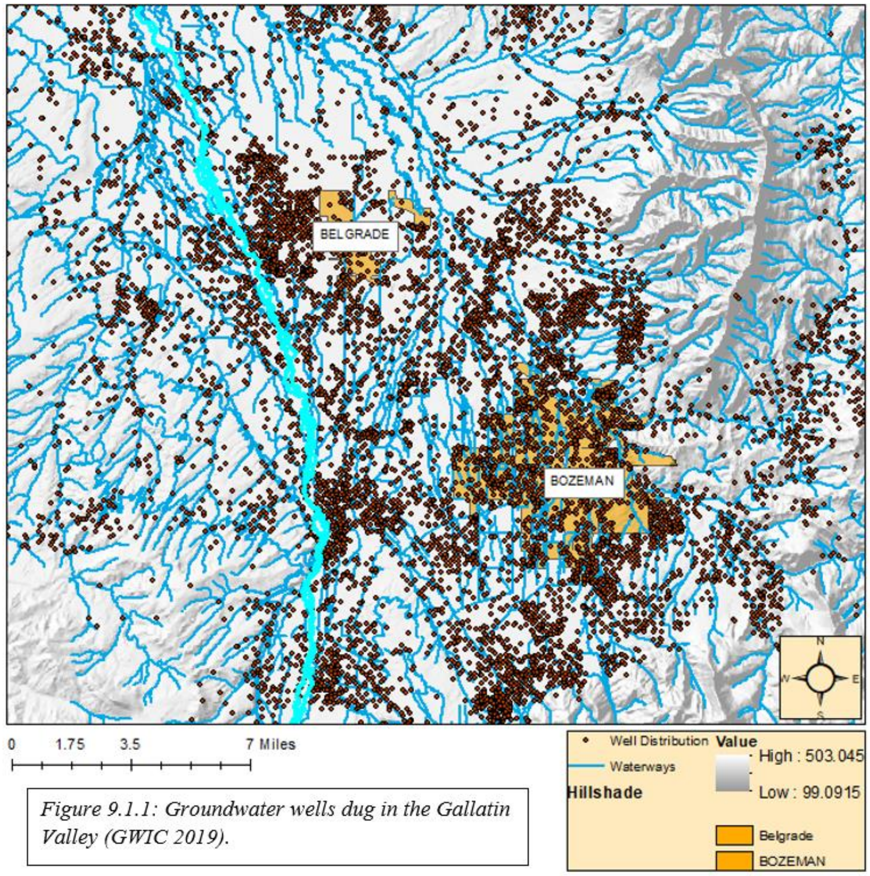


Figure 9.1.1: Groundwater wells dug in the Gallatin Valley (GWIC 2019).

In 2018, the U.S. Census Bureau released population estimates, ranking Gallatin County as the fastest growing of its size in the nation, having added 3,738 new residents between 2016 and 2017 (Kendall 2018). These numbers represent the drastic increase in population and continued growth within Bozeman and the surrounding rural areas. As these areas continue to grow, urbanization of previously irrigated land contributing to groundwater recharge could reduce overall groundwater availability while increasing groundwater consumption by the addition of new wells. An increase in housing development and groundwater rights will be necessary to accommodate incoming residents and it will be imperative for decision and policy makers to consider groundwater use and availability of the developing area before moving forward with project proposals.

Solutions for Managing Gallatin Valley's Freshwater Resources

Freshwater management should start with data collection and classification of hydrologic regimes for the Gallatin Valley. The hydrologic regime can be measured through variations in waterbody characteristics that are repeated throughout seasonal cycles. Data involving rock and soil characteristics, slope, vegetation cover, precipitation, evapotranspiration, stream water flow, and groundwater depth can be used to define the connection between ground and surface water. When net depletion of ground and surface water has been identified, this information can act as a map for important recharge zones that may need to be assigned as controlled groundwater areas which will limit groundwater use and could help to sustain both surface and groundwater availability in the Gallatin Valley.

Recognizing surface and groundwater as one source could take many years of convincing data analysis and significant deliberation before being implemented. However, monitoring and management plans could be the foundation necessary to help kickstart awareness and data needed for implementing the recognition. The relationship between groundwater and surface water is complex and stakeholders must share varying skills and data sets to better understand these interactions for future water management in the Gallatin Valley.

9b. Population and Drying of the American Southwest

Joseph Thomason

The Southwest is the most hot and dry region of the United States. The region is comprised of nearly 70 million people throughout six states; Colorado, Utah, Nevada, Arizona, California, and New Mexico. By 2050, the population is estimated to increase by 68% to nearly 100 million people making it the fastest growing region in the United States (Garfin et al. 2014). Most areas within the Southwest receive only 5 to 15 inches of precipitation in an average year, while the eastern US averages 50 to 60 inches of precipitation in comparison (Water Allocation . . .2015). As the Southwest is unable to rely on local precipitation for water, storage in large reservoirs, canals, and aquifers has allowed it to develop thus far. With climate change, the Southwest is expected to become drier as a result of rising temperatures and altered precipitation and snowpack patterns. The region is already heating; conditions today are the hottest seen in at least 600 years with an average increase of 3°F, with increased duration and temperature of heat waves (Garfin et al. 2014). Temperatures are projected to increase by 9.5 °F by 2070, directly impacting water supply and creating unsafe or even inhospitable conditions for humans and all other species within the environment (Garfin et al. 2014). Also by 2070, there will be more than a 60% decrease in projected average snowpack (Garfin et al. 2014). It is likely large reservoirs and aquifers will become obsolete and the ability to store water will subside. Although the Southwest is notoriously arid, the people who reside within the region use 80 to 100 gallons of water per day, on average, for just indoor home uses such as flushing and bathing (Dieter et al. 2019). The region is also responsible for more than half of the nation's high-value speciality crops and yields the largest production of beef, which consumes 79% of the Southwest's water supply (Garfin et al. 2014, Water Allocation . . .2015). Growing alfalfa in the Southwest takes up to 4 times as much water than in other regions with cooler and wetter climates (Baines 2014). It is estimated that it takes 1000 gallons of water to process the beef for only one double quarter-pound hamburger at McDonald's (Baines 2014). In consideration of climate change, development, and modern usage, human and environmental water demands will be prone to devastation without change. Is it appropriate to use water in such a way considering anthropogenic climate change? Can one limit development or stop an industry such as the beef industry? Could you change or regulate a whole society to alter their bathing habits or change their plumbing infrastructure?

The foundation for western water rights began during the gold rush in 1848 when water was needed to mine for gold. Rather than establishing rules to distribute water, early settlers created a system called 'prior appropriation,' which is another term for 'first come first serve' (Water Allocation . . .2015). During a drought, the person with prior appropriation is allotted their water first. This was well before environmentalism, cultural awareness, or even women's right to vote. Prior appropriation is still in place today. During the induction of reservoirs and canals in the mid 1900s in the Southwest, allocations were set into place to help dictate future water decisions. States established a hierarchy of uses with domestic use in cities being the number one priority followed by agriculture, and then industrial uses (Water Allocation . . .2015). During the time allocations were written, there was no such thing as the Environmental Protection Agency or the Endangered Species Act. Water was stripped from ecosystems and ultimately decimated one of the most biodiverse regions in the world, the Gulf of California, where thousands of species would migrate during the winter season. Today, water does not even reach the ocean as more than 90% of water gets distributed before reaching Mexico (Baines

2014). Today, nearly 90% of the Southwest population resides within cities, and have large portions of water rights that many species depend on (Garfin et al. 2014). Cities such as Las Vegas use 70% of their water to irrigate their 60+ golf courses (Baines 2014). The average American shower uses 17.2 gallons alone and an older faucet will dispense up to 4 gallons of water per minute (Dieter et al. 2019). Endangered species that used to thrive, with population sizes in the millions pre-westernization, rely on water. Species such as the California Condor or the Colorado Pikeminnow face extinction today due to lack of habitat because of water decimation. Not only is there unfair distribution amongst species but amongst humans as well. Fifty-eight out of every 1,000 Native American households lack plumbing, compared with 3 out of every 1,000 white households creating an unfair separation in water access and ultimately health due to limited clean water caused by historical allocations (Morales 2019). As water acts as a finite resource today, actions must be taken to address the future considering climate change limiting water resources even further in the Southwest. With depleting water supplies, increased population, and increased environmental despair, no major alterations in water allocations or regulations have been made. Who or what gets clean water? Does someone or something deserve more water over another? Should people stop golfing? These are the questions we face considering future allocation and regulation.

Many popular ideas to provide clean water have been introduced such as desalination or importing water. These approaches take a lot of money, resources, and energy; something not everyone has. As the Southwest faces water shortages, it is embarrassing to acknowledge that less than 0.33% of all water in the US gets recycled (Water Reuse . . .2018). Recycling water costs less than half as much as desalination and has little byproduct, while 95% of water that enters the home goes down the drain (Water Reuse . . .2018). As recycling water may still be an economic endeavor for some communities, it represents a shift in the way we use water in the environment and limits our impacts. Water recycling decreases diversion of water from sensitive ecosystems, reduces and prevents pollution, and provides clean water for human applications (Water Reuse . . .2018). Water in the desert is a finite resource. The way we view water in the Southwest needs to change, as it is not unlimited and has already created major long term impacts due to its limitations. Just as paper and plastic recycling has widely spread throughout as a necessity, water needs to be reused, not remade.

9c. Plastic Pollution in the Great Lakes

Natalie Crane

Introduction

The Great Lakes hold 20% of the world's freshwater reserves and provide drinking water to more than 40 million people across North America. Plastic byproducts have been documented in a diverse range of freshwater ecosystems, reaping complex and in some cases, irreversible consequences. More than 22 million pounds of plastic pollution ends up in the Great Lakes each year (Rochman 2019). Urbanization, population growth, and improper waste management have largely contributed to this widespread problem. Because of this, freshwater scientists have become increasingly interested in studying the damage that plastic accumulation causes, and what effects these build-ups have on water quality.

History

Canada and the United States signed the Great Lakes Water Quality Agreement (GLWQA) in 1972 with hope of protecting their shared freshwater resource, the Laurentian Great Lakes. A major parameter of the GLWQA was the expressed intent by both countries to reduce loading-caused eutrophication. The agreement was revised in 1978 to undergo agency review, now including plastic cap provisions and a plastic litter budget. The impressive size of the Great Lakes has not been enough to shield them from water quality problems, resulting from tremendous population growth throughout their basin. Over the past 180 years, the population of the Great Lakes region has risen from approximately 300,000 to more than 40 million (De Pinto et al. 1986). Since this immense population growth, and throughout the development of industrialization, the Great Lakes' water quality has steadily deteriorated.

Research

Since plastic was first detected in the ocean over 40 years ago, understanding the effects of plastic pollution on oceanic systems has been the focus of extensive research. Not until recently has similar concern been brought to freshwater. The presence of microplastics - plastic particles <5 mm - has been confirmed in surface water, beaches, sediment, effluent areas, and in rivers that directly feed into the Great Lakes (Cable et al. 2017). Some areas of the Great Lakes have higher surface water concentrations of plastic than ocean gyres (Bhateria and Jain 2016).

Nearly 2 million fragments km^{-2} were found in the Detroit River alone - substantially surpassing previous reports of plastic concentration in Great Lakes tributaries. In 2014, plastic distribution was assessed across three Great Lakes: Lake Superior, Huron, and Erie. Surface water was collected at 38 stations in river plumes, basins, and in effluent areas from May to August. Plastic was found at all 38 stations, with the majority being <1 mm. The highest concentrations of plastic were found within 12 km of populated cities, while the lowest counts were collected at non-urban stations. Lake Erie respectively had plastic concentrations 80-fold higher than Lake Huron and Superior. Although Lake Erie is the smallest and shallowest of these lakes, it has the highest surrounding population and is most used for the fishing and shipping industry (Cable et al. 2017). The plastic debris found in Erie consisted of pellets, fragments, foam pieces, film, and fishing line (Bhateria and Jain 2016). This study also analyzed percentage of the watershed that was comprised of impervious soil, and found it to be positively correlated with higher plastic concentrations - likely due to a greater volume of runoff from urban areas with increased human activity and plastic production. Considering how long it takes plastic to degrade and the lakes' residence times, fragments of some of the first plastic ever produced are likely still present in the Great Lakes (Cable et al. 2017).

High concentrations of microplastics (up to 4,270 microplastics per kilogram of lake sediment and 2,444 microplastics per kilogram of river sediment) are present in Lake Huron, Ontario, Erie, St. Clair and their tributaries, and are becoming part of their benthic environments (Microplastics in… 2019). These microplastic fragments stick to organic compounds and accumulate on pollutants such as pesticides, trace metals, and pathogens (Rochman 2019). The microplastics found in lake bottom sediment are especially abundant near industrialized areas with plastic production sites. Nearly 13,000 plastic pellets were found on a Lake Erie beach - about 1/8 the area of a football field. Plastic pellets are derived from petroleum products and are about the size of a pea. Most of these pellets are found near tributaries, as creeks and rivers are the main transporters of plastic into the Great Lakes.

Relevance

How is this contamination impacting humans, considering our reliance on clean water for survival and livelihood? Billions of people around the world are drinking water that's been contaminated by plastic (Carrington 2017). Scientists from an investigation by the Minnesota

School of Public Health sampled the tap water of 159 locations across the Midwest, and found plastic fibers present in 94% of the samples. Although the passage of larger particles can be prevented, technology has yet to be created with a level of filtration to catch microfibers (plastic fibers with diameter <10 microns). In addition to contamination, there is concern for the passage of harmful chemicals and pathogens that are often bound to plastic particles (Carrington 2017). The freshwater resources provided by the Great Lakes are vital for not only drinking water, but for the economies of Midwest communities. Their livelihoods depend on recreation, tourism, and the fishing industry - all of which are threatened by poor water quality.

Proposed solutions

Plastics are transported to the Great Lakes by a network of streams and rivers from non-point sources. In other words, it's very difficult to pin point the exact origins of this debris. This raises the question of who is responsible for cleaning it up and who should pay for it. Several private organizations and non-profit sectors have been working to find solutions to this problem. One proposed solution is to further develop innovative technologies, such as radio-frequency tags and collection barriers to gather the plastics (Sigler 2014). However, this approach won't work with microplastics, being that they're too small to be successfully collected. Recycling can reduce the impact of plastic consumption, however very rarely does a recycled product end up in its intended location. The Massachusetts Institute of Technology has developed a "trash track" cellular transmitter network that will hopefully help researchers better understand the U.S. waste management system and how so much litter ends up in freshwater (Sigler 2014). But even with recycling, research, and new technology, the only identifiable solution is to cut back on plastic products and integrate more sustainable alternatives into the market.

Conclusion

Research efforts towards plastic pollution are expensive, complex, and time-consuming. As a result, studying its effects on the quality of our freshwater, and on human health, has not yet come close to resolution. Plans to combat the plastic crisis in the Great Lakes will cost more than $400 million annually (Bhateria and Jain 2016). I would argue that we are ethically obligated to avoid and decline plastic products, and demand a production system that recognizes the effects of this type of consumption. Is it ethically responsible to be utilizing this freshwater resource for drinking water, granted we know it's contaminated? What does this mean for our continental freshwater supply? Unfortunately, the full extent of these impacts is currently unknown. While studies on plastic pollution in freshwater continue to advance, it remains extremely difficult to obtain accurate and representative data using plastic counts (Cable et al. 2017). We, as environmental scientists, must utilize our shared knowledge and expertise to find more effective ways to tackle this problem. We are obligated to analyze these human impacts with non-bias and thoroughness, and produce valuable research for the good of our Earth. We must realize the sense of urgency that is at hand, and come together to begin to understand, and hopefully improve, environmental issues such as this one.

9d. Water Availability in the Pacific Northwest

Kesslie Carlson-Ham

The Pacific Northwest is defined by the vast river basin covering much of Washington, Oregon, Idaho, and parts of British Columbia and western Montana. The basin is greater than 275,000 square miles (Boundary Desc... 2019) and supplies more than ten million people with fresh drinking water, irrigates over eight million acres of agricultural land, and produces over 50% of the northwest’s energy resources from hydroelectric power (Pacific Northwest...2019). The region is divided by the Cascade Mountain Range, creating two separate climate regimes for the same basin; east of the Cascades the climate is hotter and drier, receiving nearly one tenth of the yearly precipitation than that of the western portion where average annual rainfall can reach 100 inches at higher elevations and more than 30 inches in lower lying areas. West of the Cascades the climate is subject to more maritime weather influence, rainfall is frequent and temperatures are mild in comparison to the eastern portions of the Pacific Northwest (Huang et al. 2015). From October through May, much of the precipitation that falls west of the Cascades is stored in the mountains as snowpack which accumulates until temperatures begin to rise in the summer months and snowmelt occurs, replenishing streamflow both east and west of the Cascades when precipitation is lowest and water demand is highest. For this river basin; and many others like it around the world, winter snowpack is directly linked to summer streamflow, and the water availability within the region depends heavily on an abundant and consistent amount of precipitation being stored this way to support the existing water demands of the

Pacific Northwest. Due to increasing global temperatures anthropogenic climate change poses a unique threat to this region.

Regionally, the average temperature has increased 1.3 °F from 1895 to 2011. As warming continues models project a rise in average temperatures up to 3.2 °F by the year 2040, leading to a severe swing in precipitation in both form and severity (Kunkel et al. 2013). Increased amounts of precipitation as rainfall during the autumn and winter are predicted as well as reduced precipitation and higher temperatures during the summer months (Littel et al. 2009). The increase of rainfall along with rising average temperatures leads to a decrease in accumulated snowpack which has been observed from 1955-2016 as a 23% decline across Oregon, Washington, and the Northern Rockies (Mote and Sharp 2016).

Figure 9.2 illustrates the decline of Snow Water Equivalent (SWE) in snowpack in the western United States. SWE is the measure of water contained within the snowpack and allows for close estimation of the amount of snowmelt and spring streamflow that will result from the precipitation. Not only is there a decrease in annual snowpack, decreasing the amount of water availability in the summer months, but the average spring snowmelt is occurring earlier than historically recorded (Capalbo et al. 2014). With spring snowmelt occurring earlier in the year so does the peak spring streamflow, deteriorating water resources that would normally persist throughout the summer maintaining streamflow in both western and eastern portions of the Pacific Northwest.

As snowpack in the Cascade Mountains decreases, there is likely to be a plethora of side effects that stem from lack of water availability and other climatic influences. While all of the Pacific Northwest will experience the decrease in snowpack each region will undergo very different consequences. East of the Cascades will experience greater drying effects as the climate regime is subject to continental weather patterns and has much less rainfall than west of the Cascades. Increased summer temperatures combined with lack of precipitation and streamflow within the region is projected to lead to drought and subsequent increase in wildfire vulnerability and intensity (Littel et al. 2009). West of the Cascades will receive a larger number of flood events during the fall and winter when precipitation is highest, and average temperatures will rise to a level at which snowpack cannot accumulate and instead turns into rapid runoff. As coast lines endure the effects of rising sea levels, increased fall and winter flood events will inundate

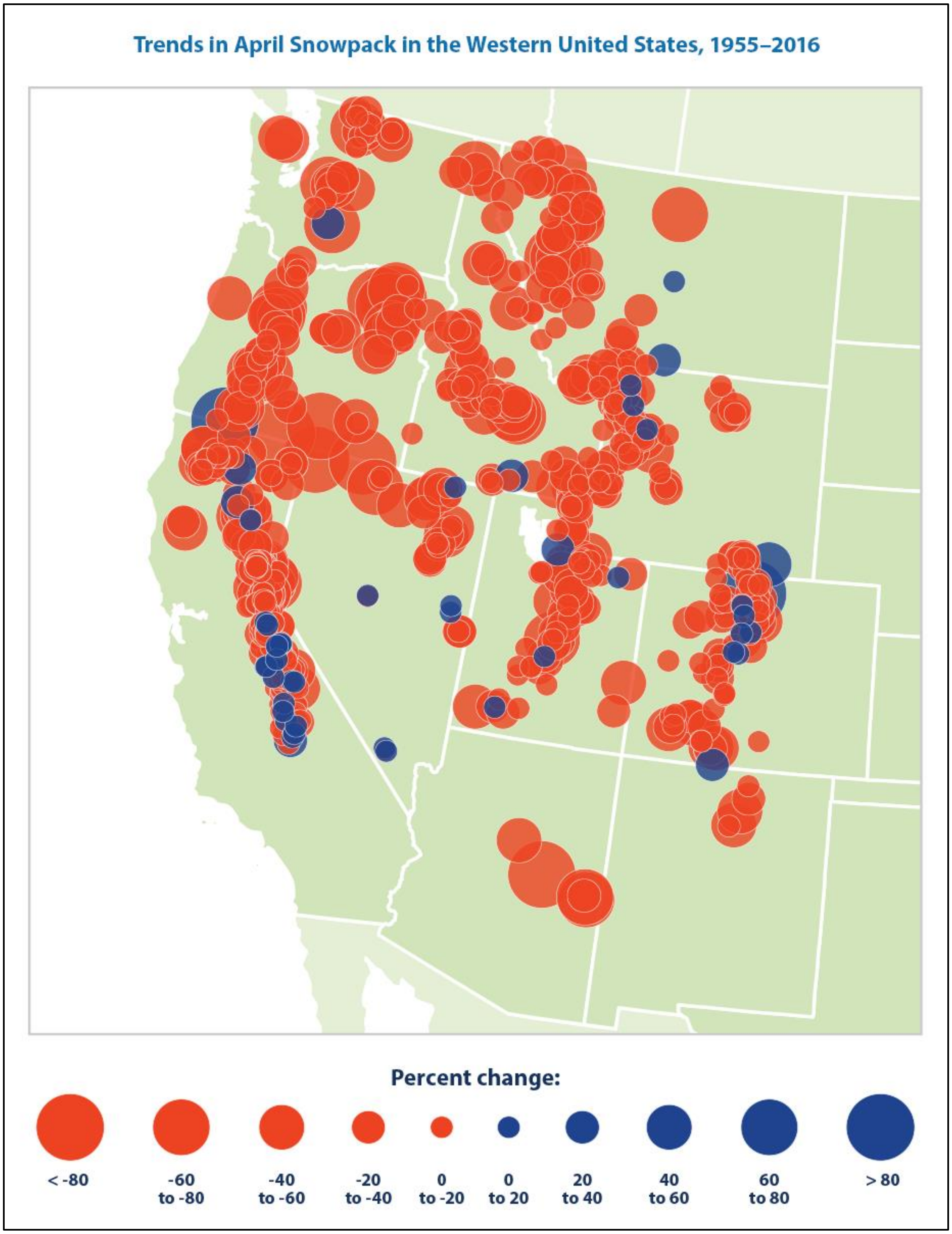


Figure 9.2. *Trends in April snowpack in the western United States, measured in terms of snow water equivalent (SWE); (Mote and Sharp, 2016).*

much of the low lying coastal areas for prolonged periods before total inundation (Capalbo et al. 2014). Potential damage to wetlands, agricultural land, and infrastructure could be catastrophic.

The impacts of decreased snowpack and reduced summer streamflow also extends significantly to the wildlife endemic to the region. The Pacific Northwest is home to several different salmon species; inland streams serve as spawning grounds where roe is cached into gravel rock beds, estuaries provide space for young salmon to reach maturation before migrating to the ocean, and marine habitat allows for growth before their journey back upstream. Each portion of the aquatic ecosystem is extremely important for the continuation of the salmon spawning cycle. Combined rising average air and stream temperatures causes water quality issues and thermal stressors for both young and mature salmon including low levels of dissolved oxygen, stagnation of toxic sediments, and increased disease proliferation (Richter and Kolmes, 2005). Increased flood events dislodge vulnerable spawning nests, forcing young salmon into the ocean before they've reached full maturity (Littel et al. 2009). Salmon productivity is strongly linked to water temperatures at every stage of life, years of high productivity have been linked to years of cold inland and coastal temperatures with deep snowpack. With declining snowpack, declining streamflow, and increasing air and stream temperatures several endangered or threatened salmon species could reach temperature thresholds in which survival is not possible (Richter and Kolmes, 2005). Due to the ecological importance of salmon as a keystone species the decrease in salmon populations has a cascading biological impact on numerous other species and the forested and marine ecosystems they have historically run.

The water availability issues facing the Pacific Northwest are not limited to this region; many river basins throughout the world are also snowmelt driven and rely on snowpack to provide water for sociological, economic, and environmental needs. If the current trajectory of climate change and water usage continues, there will be inevitable water shortages and water quality impacts. With robust evidence supporting climate change and its subsequent consequences, it is ethically unsound for an informed community to choose inaction over adaptation. As predicted by the National Climate Assessment in all climate scenarios there will be a reduction in streamflow by 2050 in river basins such as the Pacific Northwest (Capalbo et al. 2014). The adaptive capacity of this region is higher than most, due to the current abundant water resources, lower system sensitivity, progression of alternative energies, and various management agencies that pursue monitoring and allocation. However, large scale climate action and water resource planning needs to occur for the Pacific Northwest to be able to combat the effects of anthropogenic climate change that are already taking place. The climate action plans of

Oregon and Washington call for focus on areas of high risk, regions such as those found east of the Cascades (Capalbo et al. 2014). Water availability is most sensitive in these areas and will likely be the first to show major climate change impacts. Implementation of efficiency practices and conservation tactics within municipal, industrial, and agricultural systems must be adopted in order to effectively plan for water allocation in the future. As water becomes less available each sector will need to coordinate and compromise to meet the demands necessary for a viably sustainable economy, environment, and society. On an individual level it is the ethical responsibility of environmental scientists to make decisions that reinforce the information we find to be strongly supported, encouraging proper management and adaptability. Impending anthropogenic climate change can be curbed as long as there is action as opposed to inaction; it is the responsibility of the scientific community to aide in the progression of ethical climate change discussion and decision making in order to catalyze such action.

9e. The Ethical Issues of Water Scarcity and Desalination in the Middle East and Northern Africa

Kathleen Mitchell

Here. There. Gone. In a blink of an eye, water, a natural resource that life depends upon is disappearing before our eyes. Water scarcity is an increasing issue that we are tackling globally. Making up 70% of the earth, (Kummu et al. 2010) water seems abundant, but only 3% of the world's water is fresh water and two thirds of that water is unavailable for human use (Kummu et al. 2010). As a result, roughly 1.1 billion people throughout the world lack access to clean drinking water and in growingly arid regions, water scarcity concerns are rising to dangerously new levels (Kliot 2005). The Middle East and Northern Africa are currently facing one of the most severe water scarcity threats on the globe (Kliot 2005). The water threats found in the Middle East and Northern Africa are largely due to growing populations, industrialization and desertification (Kliot 2005). The lack of water is having major negative impacts on the thousands of communities that occupy this land. In an already increasing arid environment, agricultural productivity has decreased, thus lowering household's average income and reducing the labor force (Hussein 2011). Water scarcity in the Middle East and Northern Africa has also increased the tension between the rich and the poor, the government and civilians and neighboring countries (Baconi 2018). With the destructive impacts on communities and the increasing lack of water, the Middle East and Northern Africa need to continue efforts to ensure access to safe drinking water. One way that these areas are accomplishing this is by the process of desalination.

Desalination is a new method used to increase water supply. Desalination removes salt and other minerals from water harvested from the sea. This is done by multiple different water purification processes such as reverse osmosis and condensation. Desalination is most commonly accomplished by reverse osmosis which forces sea water through different thin membranes at high pressures separating the salt from the water (Walton 2019). Desalination plants are common in the Middle East and are owned by countries such as Saudi Arabia, United Arab Emirates and Kuwait among many more (Walton 2019). Most of the desalination plants in the Middle East are located along the coast of the Red Sea (Hoepner and Lattemann 2003). This is due to many countries' proximity to the Sea, transportation costs as well as the abundance of water (Yangali-Quintanilla et al. 2011). Although desalination is used to combat water shortage, it requires a lot of energy and fossil fuel consumption (Hafez and El-Manharawy 2003). Two thirds of the desalinated water in the Middle East is produced using fossil fuels, while the rest relies heavily upon electricity and natural gasses (Walton 2019). It is predicted that by 2040, three quarters of the water produced in the Middle East will still rely heavily upon fossil fuel-based electricity increasing the regions total energy consumption by 15% (Walton 2019).

The increase in desalination is not only fixing a depleted resource but also having ethical and physical implications on the environment. The heavy use of fossil fuels controlling these plants is unsustainable and produces a large carbon footprint. Although desalination depends upon a heavy consumption of fossil fuels, there is talk of using renewable energy sources to power these plants. Solar energy is currently being tested to see if a comparable amount of water can be produced in a more sustainable way (Qtaishat and Banat 2013). The process of desalination also produces a large byproduct of salt and brine. The salt and brine waste is usually discharged back into the Red Sea or into the Persian Gulf (Hoepner and Lattemann 2003). By releasing the salt back into the ocean environments, it has increased salinity levels and caused chemical imbalances altering marine environments and destroying ecosystems. The disposal of byproducts of desalination brings up an ethical question: How far will humans change and morph natural environments for their personal gain?

The lack of safe drinking water in the Middle East and Northern Africa is not only affecting communities' resources but also causing increasing conflict and tension between countries. Many countries in the Middle East and Northern Africa share access to the same freshwater sources. These sources include many depletable underground aquifers, the Jordan, Tigris, Euphrates and Nile Rivers and many small lakes (Bulloch and Darwish 2017). With growing water scarcity and consumption, these freshwater sources are often allocated unfairly between countries thus causing conflict between them (Bulloch and Darwish 2017). Desalination is an alternative method to combat water allocation and tension between water scarce countries. A solution to further expand safe drinking water and decrease conflict would be to not only draw water from the Red Sea for desalination but to also draw water from the Dead Sea (Asmar 2003). The Red Sea-Dead Sea Canal (RSDSC) plan suggests a canal be built connecting the Red Sea to the Dead Sea (Asmar and Ergenzinger 2002) to increase the amount of desalinated water accessible to Jordan and Palestine as well as potentially form a peace treaty between the two feuding countries (Asmar 2003). The RSDSC serves not only as a practical solution to water scarcity in these countries but also an ethical solution. The RSDSC devises a solution regarding the ownership of water and allows access of clean water to everyone (Gavrieli et al. 2005). It would also effectively determine who controls the water sources and allow many citizens of many countries the right and access to depleting water as water scarcity issues intensify.

The access to safe water is a basic human right because life is a basic human right. However, roughly 2.7 billion people find water scarce for some portion of the year (Kliot 2005). The water that is available for people often is controlled by richer and more developed countries or by people with higher power inadvertently taking away people's basic water rights. The greed and power of people can often take overarching control of many water resources for wasteful and materialistic needs. Water is not only a resource needed for survival, it is one of the key foundations for how humans promote the overall well-being of a society. Water is not only a measure of human wellbeing, it also encompasses power, it is a measure of economic worth through food production, tourism, scientific development and many other factors (Bakker 2007). Although water has many values, it also demonstrates a connection to culture and many traditions. The lack of water can disconnect people from their culture, their society, their environment and the global development of the world (Filmer-Wilson 2005). A large issue that many people in our society do not understand is that we are completely dependent upon water. From an ethical standpoint, being so water-dependent should lead to a level of responsibility to protect and maintain the resource (Liu et al. 2011). By recognizing our dependence on water, greed and power should be put aside and the realization that water cannot be considered completely for human use needs to be prevalent. As human populations continue to grow globally, climate changes rapidly and the overall consumption of water rises, it is our responsibility to conserve water. Water scarcity, as seen from above, is not only a scientific issue but also a political issue. Due to the fact that societies separate science from politics, makes water scarcity harder to solve. Scientists are often the ones who study the processes of water, the roles it has on the environment and ecosystems and the new methods to use it. By allowing scientists to not only advocate the scientific evidence of water scarcity but also its political implications could help merge the problems of this climatic event. With all of the knowledge that scientists have on the issue of water there are multiple ethical questions to consider: Is it the responsibility of science and scientists to address and solve the global issue of water scarcity? And should scientists be more involved in politics to help bridge the gaps between public opinions and scientific evidence?

Community Based Global Water Conservation for A Changing World

Katya Koepsel

https://www.liberationnews.org/wp-content/uploads/2015/04/o-WATER-SHORTAGE-facebook.jpg

Water creates civilization. I see wilderness as water, our aquifer as human beings that ties us to the whole of this planet, the water that allows us to drink deeply from the source of community that comprises all life not just the culture of our own species

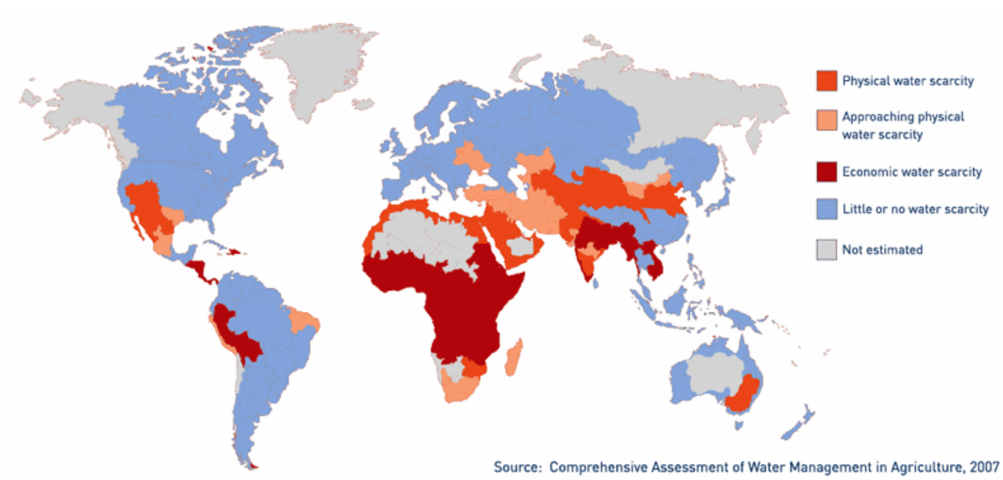
-Terry Tempest Williams

In a changing global climate, water availability will be the defining issue of our time. In the past human civilizations have lived and died as a result of changing water availability. The pressure on future global freshwater resources could leave billions of people without adequate water access and radically disturb freshwater ecosystems.

Global Water Resources

Unpolluted, clean and safe water is necessary not only for anthropogenic purposes but also to maintain functional aquatic ecosystems. The Earth's global water resources consist of 97.5% salt water and 2.5% freshwater, however of freshwater only 30.5% of the 2.5% is available for human and freshwater animal uses. This means that the resource is already quite limited and the need for clean water is only increasing over time. Per Capita human water use has doubled over the past 100 years per capita (Black 2016).

Around the world many regions are facing similar water conservation issues. In arid areas major river systems are overused and sometimes are completely dry before they reach the ocean. In the high elevation subtropical regions of the world such as the Himalayas and the northern Andes, glacial melt and snowpack driven watersheds have supplied rivers. With receding glaciers, warming global temperatures and more erratic weather patterns these water systems are at risk for reducing water availability. Global water usage is also inherently disproportional; with water users in developed countries use vastly more than those in developing countries (Jennewein 2016).



http://www.21stcentech.com/wp-content/uploads/2012/03/water-scarcity-map.png

Groundwater has been seen as a resource that could always be relied on for anthropogenic uses. This however will not continue to be true. Groundwater resources, formed by deep infiltration of surface water into underground aquifers, can hold water that is millions of years old called "fossil water". Fossil water is an unrenewable resource because of the extremely long timescale that it has taken for this water to accumulate. Groundwater loss is expected to have devastating effects in countries in the Middle East and Northern Africa such as Yemen, Iran, and Libya which rely almost exclusively on it, in the next several years. Currently about 1.5 billion people rely on groundwater for survival (Black 2016).

Threats to Global Water Availability and Quality

Pollution

One of the most immediate pressures on our water supply is anthropogenically- caused pollution. One of the largest sources of freshwater pollution is untreated human waste. In developing countries about 90% of all wastewater is discharged into water systems completely untreated. Another large source of freshwater pollutants is agriculture where fertilizer from fields runs off into waterways. This causes large spikes in nutrients in freshwater especially nitrogen and phosphorous. These two potentially limiting nutrients can enter waterways and cause harmful algal blooms (HAB's) due to excessive algal growth. HAB's make water undrinkable and pose human and livestock health hazards (Moursi 2017).

Overallocation and Potential Global Conflict

Due to political and social dynamics many watersheds and river systems are under the jurisdiction of different communities, states or even countries. Around 260 of the world's river basins are shared by two or more countries (Black 2016). This has a great potential to lead to conflict especially between players on the international stage. One example of international water conflict related to overallocation is the Colorado River Compact between the United States of America and Mexico. The compact was established at a time when water resources were thought to be more abundant than is actually true. This caused the Colorado river to barely flow across the US Mexico border which has had disastrous effects on the lives of people in the area and the ecology of the environment. The Colorado River's flow has been predicted to decline by a further 9% over the next 50 years due to climate change.

There are likely to be future political conflicts between countries such as Bolivia and Chile, the countries of the Nile River Basin, China, India, Bangladesh, and Pakistan. Many of these political conflicts have been increasing over time and will continue to plague these countries as water scarcity intensifies and human populations increase.

Community Based Resource Conservation as a Viable Solution

People are most likely to conserve resources in their own communities because they can see and feel the results more immediately. This makes community-based water resource conservation an effective approach to solving global water shortage problems. This solution can be applied at any scale as long as people are willing to commit to the decided upon conservation techniques (Jennewein 2016).

The maintenance of healthy watersheds, responsible water management, and conservation is essential to maintaining the planets most critical resource.

Water Conservation Solutions

The goal of this project is to create a global resource toolkit with information that can be used by people in any community in any region to improve their water conservation practices. The conservation methods are achievable with little monetary costs and are aimed to be simple enough to be practiced by anyone with minimal training. The resources are meant to be made widely available to community leaders and organizers.

- **Rainwater catchment systems** can be effective at capturing water that is shed off of rooftops and other non-permeable structures. These can be as simple as pipes coming off a rooftop attached to a large bucket. This option allows for rainwater to be collected for drinking before it hits the earth's surface and has the potential to become contaminated. Studies by the United Nations University International Institute for Global Health in Uganda indicate that one of the biggest problems with rainwater harvesting in developing countries is that there is not enough education for users on how to properly use and maintain rainwater catchment systems (Baguma 2012).

- **Education materials to reduce agricultural nutrient pollutants** in water can be helpful in maintaining clean water sources that are near agricultural areas where nutrient additions have contributed to compromised ground and surface water resources. If water contamination can be prevented, it will remain a cleaner, healthier and more usable part of the ecosystem and will be able to be used more productively.

- **Investment in water saving faucets and shower heads** for countries and communities where they are applicable, would be effective at reducing water use. Switching from a 2.5 gallon per minute shower head to a 1.5 gallon per minute shower head can reduce water usage by up to 60%. These solutions may not be valuable in communities that don't have as much financial capital.

- **Reduction in unnecessary irrigation in arid regions** could reduce the total amount of water needed in some parts of the world. One example of this is in Yemen where 45% of pumped groundwater is used to irrigate khat, an addictive narcotic. If this was not being used to grow narcotics it would contribute to a better quality of life for Yemen's people and also allow for more of their water resources to be used for basic human and environmental needs.

- **Reducing total water consumption of agriculture** would be the most effective water saving strategy globally. According to Balsher Singh Sidhu from TED-Ed, 92% of total human water consumption is for agriculture. Reducing food waste and reducing the production of red meat and tree nuts, which are some of the most water intensive food products, could be the most effective solution for global water conservation (Studio K. A. 2018).

Overall global cooperation and changes in water availability expectations are necessary to continue our current level of environmental quality with an increasing human population and increased pressures on global resources. Using the above solutions, which are not exhaustive, progress can be made to ensure that water resources remain available and adequate for the future.

10. Final Summary and Conclusion

The ethical dilemmas we are faced with as environmental scientists are intricate and complex. The sheer magnitude of issues and subsequent questions which arise can be stifling. However, as we approach each subject from an ethical standpoint we hold a better understanding of how important these considerations can be in the field of environmental science and for the persistence of a sustainable society. While historically exclusive, science and ethics have now become inextricably linked as the world encounters new obstacles for a thriving global economy and healthy environment on a near daily basis. Environmental issues that were once seen as an unavoidable consequence of continued development are now being called into question as the repercussions of generations worth of poor policy and decision making has left seemingly insurmountable complications. With the progression of environmental science surging to the forefront of advocacy and policy, ethical considerations must be weighted of equal importance as these issues can no longer be ignored.

As graduates of the Land Resources and Environmental Science department of Montana State University, we will continue to encounter questions regarding food, energy, water, and resource management of our forests and oceans. The tremendous anthropogenic influences of growing populations, conversion of landscapes, and resource extraction, will forever be the hurdles that the scientific community will need to overcome. Raising the ethical questions that accompany these issues will be our responsibility and spreading education and awareness will be our duty. Forthcoming environmental scientists must be able to adapt to a new global outlook in which science and research not only advances technology and information, but also considers the moral and ethical outcomes.

11. References

Introduction References

Broad, C. D. 1985. Ethics.*in* C. Lewy, editor. Dordrecht : Springer Netherlands : Imprint: Springer.

Bourke, V. J. 1968. History of ethics. Garden City, N.Y. : Doubleday, Garden City, N.Y.

Kolata, G., S.-L. Wee, and P. Belluck. 2018. Chinese Scientist Claims to Use Crispr to Make First Genetically Edited Babies. The New York Times. Associated Press.

Weintraub, K. 2019. Genetic Mutation in "CRISPR Babies" May Shortern Life Span. Scientific American. Springer Nature Publications, Medical & Biotech.

Kraft, P., M. Lodge, and C. S. Taber. 2015. Why People "Don't Trust the Evidence": Motivated Reasoning and Scientific Beliefs. Ann. Am. Acad. Polit. Soc. Sci. **658**:121-133.

Briggle, A., and C. Mitcham. 2012. Ethics and Science An Introduction. Cambridge University Cambridge, UK.

Chapter 2 References

16 USC Ch.83: Coral Reef Conservation. 2019. Office of the Law Revision Counsel [accessed 2019, November]; https://uscode.house.gov/view.xhtml?path=/prelim@title16/chapter83&edition=prelim

A Living Reef Give Our Islands Life. 2004. Coral Reef Outreach Network. [accessed 2019, November]; http://www.hawaii.edu/ssri/cron/files/pr_fs-facts.pdf

America's Coral Reefs. 2018. EPA. [accessed 2019, November]; https://www.epa.gov/coral-reefs/americas-coral-reefs

Bayraktarov, E., P. J., Stewart-Sinclair, S., Brisbane, L., Boström-Einarsson, M. I., Saunders, C. E., Lovelock, … K. A., Wilson. (2019). Motivations, success, and cost of coral reef restoration. *Restoration Ecology*, *27*(5), 981–991.

Brown, Julie. 2012. Coral Reef Food Web. National Geographic. [Accessed 2019, December 2]; https://www.nationalgeographic.org/media/coral-reef-food-web/.

Carpenter, K. E. M. Abrar, ... E. Wood. 2008. "One-Third of Reef-Building Corals Face Elevated Extinction Risk from Climate Change and Local Impacts." Science. [Accessed 2019, December 2]. https://science.sciencemag.org/content/321/5888/560?casa_token=MKmqO3N5pHMAA AAA:ZemYLrMh3IRXoMJRN9pgv00h8HfYKhHKBoo0IBfdgYW-LrNaCPi4YTFlYLA7Bx3aReMkK_f95SJEUQ.

Carson, R. 1962. Silent Spring (First edition). Houghton Mifflin.

Castro, P., and M. E. Huber. (2016). Marine biology: Peter Castro, Michael E. Huber (10th ed.). New York, NY: McGraw-Hill.

Coral and Live Rock Rules of Hawaii. 2019. State of Hawai'i-Division of Aquatic Resources. [accessed 2019, November]; https://dlnr.hawaii.gov/dar/habitat/coral-reefs/coral-and -live-rock-laws-of-hawaii/

Coral Reef Biodiversity. 2019. Coral Reef Alliance. [accessed 2019, November]; https://coral.org/coral-reefs-101/coral-reef-ecology/coral-reef-biodiversity/

Coral Reef Ecosystems: Valuable and Threatened. 2019. The National Oceanic and Atmospheric Administration. [accessed 2019, November]; https://coralreef.noaa.gov/about/welcome.html

Dahlman, L. and R. Lindsey. 2018. Climate Change: Ocean Heat Content. The National Oceanic and Atmospheric Administration. [accessed 2019, November]; https://www.climate.gov/news-features/understanding-climate/climate-change-ocean-heat-content

Gates Coral Lab. (n.d.). [accessed 2019, December 4]; http://gatescorallab.com/.

Glusac, E. 2018. Hawaii Passes Bill Banning Sunscreen That Can Harm Coral Reefs. The New York Times. [accessed 2019, November]; https://www.nytimes.com/2018/05/03/travel/hawaii-sunscreen-ban.html

Graham, Nicholas A. J., S. K. Wilson, S. Jennings, N. V. C. Polunin, J. Robinson, J. P. Bijoux, T. M. Daw. 007. "Lag Effects in the Impacts of Mass Coral Bleaching on Coral Reef Fish, Fisheries, and Ecosystems." Society for Conservation Biology, John Wiley & Sons. [Accessed 2019, December 2]; https://conbio.onlinelibrary.wiley.com/doi/full/10.1111/j.1523-1739.2007.00754.x?casa_token=Bk_Yl0egCTgAAAAA%3A4ot315P6z_h4iGBFxtpTwQnBYFDUVuvUZV2CdBIXcVXcH8w0zqjjQwAx13zrnB8Nqg9qvO3B7bhMFw.

Grigg, R. W. 1995. Coral reefs in an urban embayment in Hawaii: a complex case history controlled by natural and anthropogenic stress. Springer. [accessed 2019, November]; https://link.springer.com/article/10.1007/BF00334349

Grigg, R. W. 2006. Depth limit for reef building corals in the Au'au Channel, S.E. Hawaii. Springer. [accessed2019, November]; https://link.springer.com/article/10.1007/s00338-005-0073-6

Grimsditch, G. 2019. Marine heat waves kill corals quicker than previously thought. UN Environment Program. [accessed 2019, November]; https://www.unenvironment.org/news-and-stories/story/marine-heatwaves-kill-corals-quicker-previously-thought

Hawai'i's Coral Restoration Nursery. 2019. [accessed 2019]; https://www.pacificrisa.org/2019/05/15/Hawai'is-coral-restoration-nursery/

Hoegh-Guldberg, O., P. J., Mumby, A. J., Hooten, R. S., Steneck, P., Greenfield, E., Gomez, … M. E. Hatziolos, 2007. Coral Reefs Under Rapid Climate Change and Ocean Acidification. [accessed December 4, 2019]; https://science.sciencemag.org/content/318/5857/1737.full.

Kleypas, J., and Yates, K. (2009). Coral Reefs and Ocean Acidification. Oceanography, 22(4), 108-117. [accessed 2019]; www.jstor.org/stable/24861028

Kushner, B. 2012. Slideshow: New Report Reveals Threats to Reefs in the Coral Triangle. World Resources Institute. [accessed 2019, November]; https://www.wri.org/blog/2012/07/slideshow-new-report-reveals-threats-reefs-coral-triangle

Leggat., W., E. F. Camp. D. J. Suggett. C. M. Eakin. T. D. Ainsworth. U. Kuzhiumparambil. 2019. Rapid Coral Decay Is Associated with Marine Heatwave Mortality Events on Reefs. Current Biology. [accessed 2019, November]; https://www.cell.com/current-biology/fulltext/S0960-9822(19)30804-8

McIntyre, Alasdair D. 2010. Life in the World's Oceans: Diversity, Distribution, and Abundance. Wiley-Blackwell.[Accessed 2019, December 2];

https://books.google.com/books?hl=en&lr=&id=Vlj1gfR7yzQC&oi=fnd&pg=PR7&dq=McIntyre,+Alasdair+D.+2010.&ots=cHJBJoHhfF&sig=zOYYvqtnfeMHAPewbV5qAQXnR4M#v=onepage&q=McIntyre%2C%20Alasdair%20D.%202010.&f=false.

Munday, P. L., J.M. Leis, J. M. Lough, C. B. Paris, M. J. Kingsford. M. L. Berumen. J. Lambrechts. 2009. "Climate Change and Coral Reef Connectivity." *SpringerLink,* Springer-Verlag. [Accessed 2019, December 2]; https://link.springer.com/article/10.1007/s00338-008-0461-9.

Pratchett, M. S., S. K. Wilson, M. L. Berumen, M.I. McCormick. 2004. "'Sublethal Effects of Coral Bleaching on an Obligate Coral Feeding Butterflyfish.'" SpringerLink, Springer-Verlag.[Accessed 2019 December 2]. https://link.springer.com/article/10.1007/s00338-004-0394-x. Protecting Coral Reefs. 2019. National Ocean Service. [accessed 2019, November];
https://oceanservice.noaa.gov/education/tutorial_corals/coral11_protecting.html

Raffa, R. B. J. V. Pergolizzi Jr., R. Taylor Jr., J. M. Kitzen. 2018. Sunscreen bans: Coral reef and skin cancer. Journal of Clinical Pharmacy and Therapeutics. 44 [accessed 2019, November]; https://onlinelibrary.wiley.com/doi/full/10.1111/jcpt.12778

Reaka-Kudla and L. MarJorie. 1997. "Biodiversity II. Understanding and Protecting Our Biological Resources". Joseph Henry Press. [Accessed 2019 December 2]; https://books.google.com/books?hl=en&lr=&id=-X5OAgAAQBAJ&oi=fnd&pg=PA83&dq=Reaka-Kudla.+"Biodiversity+II."&ots=f2WmnC22cs&sig=CdEFGQfguN5RJzDCnVF81BQ3gMg#v=onepage&q=Reaka-Kudla.%20"Biodiversity%20II."&f=false

Sentman, W. (n.d.). Reef Safe Sunscreen: Our Guide to Ocean-Friendly Sun Protection. [accessed 2019, November 4]; https://www.oceanicsociety.org/blog/2140/reef-safe-sunscreen-our-guide-to-ocean-friendly-sun-protection?gclid=EAIaIQobChMI98jPhrjR5QIVhyCtBh2Qpwo6EAAYASAAEgJDrPDBwE.

Sethi and Phalguni. 1970. Record of the sea slug, Kalinga ornata Alder & Hancock. 1864 from the inshore waters of the Bay of Bengal along Chennai coast" CMFRI Repository. [Accessed 2019 December 2]. http://eprints.cmfri.org.in/8941/.

S.2429- Restoring Resilient Reefs Act of 2019. 2019. Library of Congress. [accessed 2019, November]; https://www.congress.gov/bill/116th-congress/senate-bill/2429/text

The Clean Waters Restoration Act Signed into Law. 2019. United States Senate. [accessed 2019, November]; https://www.senate.gov/artandhistory/history/minute/Clean_Waters_Restoration_Act.htm

Valentine, J. F., and K. L. Heck. 2005. Perspective Review of the Impacts of Overfishing on Coral Reef Food Web Linkages. SpringerLink, Springer-Verlag. [Accessed 2019, December 2]; https://link.springer.com/article/10.1007/s00338-004-0468-9.

What EPA is Doing to Protect Coral Reefs. 2019. EPA. [accessed 2019, November]; https://www.epa.gov/coral-reefs/what-epa-doing-protect-coral-reefs

Chapter 3 References

Allhands, J. 2019. What You Don't Know about the Water Law That Saved Arizona. Azcentral, Arizona Republic. [Accessed 2019 Dec 1]; www.azcentral.com/story/opinion/op-ed/joannaallhands/2018/01/04/lessons-groundwater-management-act-saved-arizona/1000061001/.

Amelung, F., D. L. Galloway, J. W. Bell, H. A. Zebker, and R. J. Laczniak. 1999. Sensing the ups and downs of Las Vegas: InSAR reveals structural control of land subsidence and aquifer-system deformation. Geology 27:483-486.

Arizona v. California, 373 U.S. 546. 1963. Justia Law. [Accessed 2019 Dec 1]; supreme.justia.com/cases/federal/us/373/546/.

Bell, J. W. 1997. Las Vegas Valley: Land Subsidence and Fissuring Due to Ground-Water Withdrawal. Impact of climate change and land use in the southwestern United States. Nevada Bureau of Mines and Geology, Reno, NV.

Bell, J. W., F. Amelung, A. R. Ramelli, and G. Blewitt. 2002. Land subsidence in Las Vegas, Nevada, 1935–2000: New geodetic data show evolution, revised spatial patterns, and reduced rates. Environmental & Engineering Geoscience 8:155-174.

Benson, R. D. 2011. Alive but irrelevant: The prior appropriation doctrine in today's western water law. U. Colo. L. Rev. 83:675.

Birge, D., S. Mandhan, W. Qiu, A.M. Berger. 2019. Potential for Sustainable Use of Trees in Hot Arid Regions: A Case Study of Emirati Neighborhoods in Abu Dhabi. Landscape and Urban Planning, Elsevier. [Accessed 2019 Dec 1]; www.sciencedirect.com/science/article/pii/S016920461830598X.

Brisbane City Council. 2019. Water Smart Strategy. [Accessed 2019 Dec 1]; https://www.brisbane.qld.gov.au/clean-and-green/natural-environment-and-water/water/watersmart-strategy.

Bureau of Meteorology. 2019. Severe Storms Archive. [Accessed 2019 Dec 1]; http://www.bom.gov.au/australia/stormarchive/.

Castle, S. L., B. F. Thomas, J. T. Reager, M. Rodell, S. C. Swenson, and J. S. Famiglietti. 2014. Groundwater depletion during drought threatens future water security of the Colorado River Basin. Geophysical Research Letters 41:5904-5911.

City of Los Angeles. 2016. LA River Ecosystem Restoration. Los Angeles River Revitalization. [Accessed 2019 Oct 23]; http://lariver.org/blog/la-river-ecosystem-restoration.

Cox, J. Hillier, L. Foster, R. Ellis. 2016. Effects of A Rapidly Urbanizing Environment on Groundwater. Brisbane, Queensland, Australia. 4:30-47.

Day, J., M. Moerschbaecher, D. Pimentel, C. Hall, and A. Yáñez-Arancibia. 2014. Sustainability and place: How emerging mega-trends of the 21st century will affect humans and nature at the landscape level. Ecological Engineering 65:33-48.

Deacon, J. E., A. E. Williams, C. D. Williams, and J. E. Williams. 2007. Fueling Population Growth in Las Vegas: How Large-scale Groundwater Withdrawal Could Burn Regional Biodiversity. BioScience 57:688-698.

Debuys, W. 2011. A Great Aridness: Climate Change and the Future of the American Southwest. Oxford University Press, Inc. New York, New York.

Discover Los Angeles. 2019. Historical Timeline of Los Angeles. [Accessed 2019 Oct 15]; discoverlosangeles.com.

Dunar, A. J., and D. McBride. 2001. Building Hoover Dam: An Oral History of the Great Depression. University of Nevada Press.

Garcetti, E. 2019. Mayor Garcetti: Los Angeles Recycle 100% of City's Wastewater by 2035. Office of the Mayor of Los Angeles. [Accessed 2019 Nov 4]; https://www.lamayor.org/mayor-garcetti-los-angeles-will-recycle-100-city%E2%80%99s-wastewater-2035.

Gumprecht, Blake. 1999. The Los Angeles River: It's Life, Death, and Possible Rebirth. Baltimore: Johns Hopkins University Press.

Haider, H., A.R. Ghumman, I.S. Al-Salamah,Y. Ghazaw, R.H. Abdel-Maguid 2019. Sustainability Evaluation of Rainwater Harvesting-Based Flood Risk Management Strategies: A Multilevel Decision-Making Framework for Arid Environments. SpringerLink. [Accessed 2019 Dec 1]; link.springer.com/article/10.1007/s13369-019-03848-0.

Halseth, Odd S. 1947. "Arizona's 1500 Years of Irrigation History." Bureau of Reclamation. [Accessed 2019 Dec 1]; www.usbr.gov/lc/phoenix/AZ100/1940/AZ_irrigation_history.html.

Head. L, Adams. M. 2015. Climate change in Australia. 5:175–197.

Henderson. F, Davis. C. 2016. Sustainable Water Solutions for Climate Change Adaptation. The Natural Edge Project 1:11-28.

Hinton, K. 2014. Las Vegas: Direct Potable Reuse. University of Indiana:1-29.

Jones, F. L., and J. F. Cahlan. 1975. Water: a history of Las Vegas. Las Vegas Valley Water District.

Joyce, K. J. 2004. Las Vegas water consumption: Conservation policy case study. ABAC Journal 24.

LA River Index. Quantity of Water. LA River Index. [Accessed 2019 Oct 22]; http://riverlareports.riverla.org/water-recharge/quantity-of-water/.

Land, B., and M. Land. 2004. A short history of Las Vegas. University of Nevada Press. Reno, Nevada, USA.

Lavın, M., and S. Sánchez. 1999. On how the Colorado River affected the hydrography of the Upper Gulf of California. Continental Shelf Research 19:1545-1560.

McPhee, J. 1989. Los Angeles Against the Mountains. In the Control of Nature. New York: Farrar Straus Giroux.

Moore, T. 2018. Restrictions closer as south-east Queensland water use skyrockets. Brisbane Times 15:1-8.

Morris, R. L., D. A. Devitt, A. M. Crites, G. Borden, and L. N. Allen. 1997. Urbanization and Water Conservation in Las Vegas Valley, Nevada. Journal of Water Resources Planning and Management 123:189-195.

Mulroy, P. 1993. Water Organizations in the West. Water Organizations in a Changing West, Summer Conference, June 14-16.

Mulroy, P. 2007. Collaboration and the Colorado River Compact. Nevada Law Journal 8:890.

Overview of the Arizona Groundwater Management Code. Arizona Department of Water Resources. [Accessed 2019 Dec 1]; www.azwater.gov/AzDWR/WaterManagement/documents/Groundwater_Code.pdf.

Pavelko, M. T., D. B. Wood, and R. J. Laczniak. 1999. Las Vegas, Nevada. Land subsidence in the United States: US Geological Survey Circular 1182:49-64.

Pisani, D. J. 1977. Federal Reclamation and Water Rights in Nevada. Agricultural History 51:540-558.

Protecting & Enhancing Arizona's Water Supplies for Current and Future Generations. 2019. Arizona Department of Water Resources. [Accessed 2019 Dec 1]; new.azwater.gov/.

Reisner, M. 1993. Cadillac Desert (revised ed.). Penguin USA. ISBN 978-0-14-017824-1

Roefer, P., S. Snyder, R. E. Zegers, D. J. Rexing, and J. L. Fronk. 2000. Endocrine-disrupting chemicals in a source water. Journal-American Water Works Association 92:52-58.

Rogers, J. R., and E. Moonin. 2014. Recent Southern Nevada Water History and Water Education. Pages 1106-1111 in World Environmental and Water Resources Congress 2014.

Salvaggio, M., R. Futrell, C. D. Batson, and B. G. Brents. 2014. Water scarcity in the desert metropolis: how environmental values, knowledge and concern affect Las Vegas residents' support for water conservation policy. Journal of Environmental Planning and Management 57:588-611.

Sheikh, Bahman. 1991. Long-Range Planning for Water Reuse in the City of Los Angeles. Water Science Technology 24:11-17.

Stave, K. A. 2003. A system dynamics model to facilitate public understanding of water management options in Las Vegas, Nevada. Journal of Environmental Management 67:303-313.

Steen, Francis. 2007. A Short History of Los Angeles. Early California History. [Accessed 2019 Oct 15]; http://cogweb.ucla.edu/Chumash/.

Surface Water. 2019. Arizona Department of Water Resources. [Accessed 2019 Dec 1]; new.azwater.gov/surface-water.

Tzeng, Timothy. 2011. Eastern Promises: The Role of Eastern Capital in the Development of Los Angeles, 1900-1920. California History 88:32-53.

USCViterbi. 2016. LA's Water Issue: The Jigsaw Puzzle (Part 1). USC School of Engineering. https://www.youtube.com/watch?v=Lhy_UeeHE7o.

USCViterbi. 2016. LA's Water Issue: The Missing Pieces (Part 2). USC School of Engineering. https://www.youtube.com/watch?v=YGkWGotQqW8.

Venkatesan, A. K., S. Ahmad, W. Johnson, and J. R. Batista. 2011. Systems dynamic model to forecast salinity load to the Colorado River due to urbanization within the Las Vegas Valley. Science of The Total Environment 409:2616-2625.

Villaraigosa, Antonio R. May 2008. Securing L.A.'s Water Supply. City of Los Angeles Department of Water and Power. [Accessed 2019 Nov 10]; https://planning.lacity.org/eir/8150Sunset/References/4.K.1.%20Water%20Supply/WS.13_Securing%20LAs%20Water%20Supply_2008.pdf.

Water Your Facts. 2016. Arizona Department of Water Resources. [Accessed 2019 Dec 1]; www.arizonawaterfacts.com/water-your-facts.

Welden, F. W. 2003. History of Water Law in Nevada and the Western States. Research Division, Legislative Counsel Bureau.

Werner, Shott. B. 2016. Managing Saltwater Intrusion in The Pioneer Valley, Northern Queensland, Australia: Modelling Strategies, Preliminary Results and Future Challenges. First International Conference on Saltwater Intrusion and Coastal Aquifers—Monitoring, Modeling, and Management. Essaouira, Morocco, April 23–25, 2001.

Wigginton. D, Raine. S. 2015. Water Use Efficiency and Irrigation Practices in the Mary River Catchment, Queensland. Irrigation Association of Australia 11:1-7.

Wilhelmi, Cole, and David Tucker. 2015. Regulation, Use, and Pricing of Reclaimed Water in Arizona. UNC School of Government, University North Carolina. [Accessed 2019 Dec 1]; efc.web.unc.edu/2015/10/29/reclaimed-water-arizona/.

World Population Review. 2019. Brisbane Population. [Accessed 2019 Dec 1]; http://worldpopulationreview.com/world-cities/brisbane-population/.

Chapter 4 References

Abatzoglou, J. T., and A. P. Williams. 2016. Impact of anthropogenic climate change on wildfire across western US forests. Proceedings of the National Academy of Sciences 113:11770-11775.

Agee, J. K. 1998. The landscape ecology of western forest fire regimes. Northwest Science 72:24-34.

Alexandre, P. M., et al. 2016. The relative impacts of vegetation, topography and spatial arrangement on building loss to wildfires in case studies of California and Colorado." Landscape ecology 31: 415-430.

Busenberg, G. 2004. Wildfire Management in the United States: The Evolution of a Policy Failure. Review of Policy Research 21:145-156.

Calkin, D. E., M. P. Thompson, and M. A. Finney. 2015. Negative consequences of positive feedbacks in US wildfire management. Forest Ecosystems 2:9.

Drury, S.A, P. J. G. 2008. Fire history and fire management implications in the Yukon Flats National Wildlife Refuge, interior Alaska. Elsevier.

Fernandes, P. M., and H. S. Botelho. 2003. A review of prescribed burning effectiveness in fire hazard reduction. International Journal of Wildland Fire 12:117-128.

Fischer, W. C., and A. F. Bradley. 1987. Fire ecology of western Montana forest habitat types. General Technical Report INT-223. Ogden, UT: US Department of Agriculture, Forest Service, Intermountain Research Station. 223:95

Hammer, R. B., et al. 2009. Demographic trends, the wildland–urban interface, and wildfire management. Society and Natural Resources 22:777-782.

He, T., B. B. Lamont, and J. G. Pausas. 2019. Fire as a key driver of Earth's biodiversity. Biological Reviews 94:1983-2010.

Houtman, R. M., C. A. Montgomery, A. R. Gagnon, D. E. Calkin, T. G. Dietterich, S. McGregor, and M. Crowley. 2013. Allowing a wildfire to burn: estimating the effect on future fire suppression costs. International Journal of Wildland Fire 22:871-882.

Ingalsbee, T. 2015. Ecological fire use for ecological fire management: managing large wildfires by design. In: Keane, Robert E.; Jolly, Matt; Parsons, Russell; Riley, Karin. Proceedings of the large wildland fires conference; May 19-23, 2014; Missoula, MT. Proc. RMRS-P-73. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. p. 120-127.

Ingalsbee, T. 2017. Whither the paradigm shift? Large wildland fires and the wildfire paradox offer opportunities for a new paradigm of ecological fire management. International Journal of Wildland Fire 26:557-561.

Keeley, J. E. 2012. Ecology and evolution of pine life histories. Annals of Forest Science 69:445-453.

Liang, J., D. E. Calkin, K. M. Gebert, T. J. Venn, and R. P. Silverstein. 2008. Factors influencing

large wildland fire suppression expenditures. International Journal of Wildland Fire 17:650-659.
Marlon, J. R., P. J. Bartlein, D. G. Gavin, C. J. Long, R. S. Anderson, C. E. Briles, K. J. Brown, D. Colombaroli, D. J. Hallett, M. J. Power, E. A. Scharf, and M. K. Walsh. 2012. Long-term perspective on wildfires in the western USA. Proc Nattional Academy Science USA 109:E535-543.
National Interagency Fire Center. October 30, 2019. (NIFC). www.nifc.gov
Odion, D. C., C. T. Hanson, A. Arsenault, W. L. Baker, D. A. DellaSala, R. L. Hutto, W. Klenner, M. A. Moritz, R. L. Sherriff, and T. T. Veblen. 2014. Examining historical and current mixed-severity fire regimes in ponderosa pine and mixed-conifer forests of western North America. PloS One. **9**:e87852.
Pausas, J. G. and J. E. Keeley 2009. A burning story: the role of fire in the history of life. Bioscience. 59: 593-601.
Radeloff, V. C., et al. 2005. The wildland–urban interface in the United States. Ecological applications. 15: 799-805.
Radeloff, V. C., et al. 2018. "Rapid growth of the US wildland-urban interface raises wildfire risk." Proceedings of the National Academy of Sciences 115: 3314-3319.
Schoennagel, T., J. K. Balch, H. Brenkert-Smith, P. E. Dennison, B. J. Harvey, M. A. Krawchuk, N. Mietkiewicz, P. Morgan, M. A. Moritz, R. Rasker, M. G. Turner, and C. Whitlock. 2017. Adapt to more wildfire in western North American forests as climate changes. Proceedings of the National Academy of Sciences 114:4582-4590.
Sherriff, R. L., R. V. Platt, T. T. Veblen, T. L. Schoennagel, and M. H. Gartner. 2014. Historical, observed, and modeled wildfire severity in montane forests of the Colorado Front Range. PloS one 9:e106971.
Smith, C. 2017. Wildland Fire History - Media Coverage of the 1988 Yellowstone Fires.*in* J. Holmaas, editor. National Park Service.
Stein, S. M., et al. 2013. Wildfire, wildlands, and people: understanding and preparing for wildfire in the wildland-urban interface-a Forests on the Edge report. Gen. Tech. Rep. RMRS-GTR-299. Fort Collins, CO. US Department of Agriculture, Forest Service, Rocky Mountain Research Station. 299:36.
Stephens, S. L., B. M. Collins, E. Biber, and P. Z. Fulé. 2016. U.S. federal fire and forest policy: emphasizing resilience in dry forests. Ecosphere 7:e01584.
Taylor, A. H., and C. N. Skinner. 2003. Spatial patterns and controls on historical fire regimes and forest structure in the Klamath Mountains. Ecological Applications 13:704-719.
United States Census Bureau. October 30, 2019; www.census.gov.
Van Wagtendonk, J. W. 2007. The History and Evolution of Wildland Fire Use. Fire Ecology 3:3-17.
Whipple, D. 2015. Yellowstone Ablaze: The Fires of 1988.
Williams, M. A., and W. L. Baker. 2012. Spatially extensive reconstructions show variable-severity fire and heterogeneous structure in historical western United States dry forests. Global Ecology and Biogeography 21:1042-1052.
Wright, H. E., and M. L. Heinselman. 2014. The Ecological Role of Fire in Natural Conifer Forests of Western and Northern North America—Introduction. Fire Ecology 10:4-13.

Chapter 5 References

Ali, S. H., D. Giurco, N. Arndt, E. Nickless, G. Brown, A. Demetriades, R. Durrheim, M. A. Enriquez, J. Kinnaird, A. Littleboy, L. D. Meinert, R. Oberhänsli, J. Salem, R. Schodde, G. Schneider, O. Vidal, and N. Yakovleva. 2017. Mineral supply for sustainable development requires resource governance. Nature 543:367–372.

Alonso, E., A.M. Sherman, T.J. Wallington, M.P. Everson, F. Field, R. Roth. and R.E. Kirchain. 2012. Evaluating Rare Earth Element Availability: A Case with Revolutionary Demand from Clean Technologies. Environmental Science and Technology 46:3406-3414.

Aubynn, A. 2009. Sustainable solution or a marriage of inconvenience? The coexistence of large-scale mining and artisanal and small-scale mining on the Abosso Goldfields concession in Western Ghana. Resources Policy 34:64-70.

Bloodworth, A. and G. Gunn, 2012. The future of the global minerals and metals sector: issues and challenges out to 2050. Geosciences: BRGM's journal for a sustainable Earth 15:90-97.

Boundary Waters Wilderness Threatened-Including by Top Interior Lawyer. 2019. The Wilderness Society. [Accessed date]; www.wilderness.org/articles/blog/boundary-waters-wilderness-threatened

Briggle, A., and C. Mitcham. 2012. Ethics and Science An Introduction. Cambridge University Cambridge, UK.

Chambers, D., and K. Zamzow. 2019. Documentation of Acidic Mining Exploration Drill Cuttings at the Pebble Copper-Gold Mineral prospect, Southwest Alaska. *Environments*.

Chambers, D. October 22, 2018. Online Interview

Chepkemoi, J. 2017. What Is The Environmental Impact Of The Mining Industry? WorldAtlas, [Accessed date]; www.worldatlas.com/articles/what-is-the-environmental-impact-of-the-mining-industry.html.

Cheyette, D. 2018. *Economic Value of Bristol Bay*. Bristol Bay Native Corporation, [accessed 12/1/2019];. https://www.bbnc.net/wp-content/uploads/2017/05/BBNC-Pebble-Mine-Economic-Value-of-Bristol-Bay.pdf

Ecological Impacts of Mountaintop Removal. 2017. *Appalachian Voices*. appvoices.org/end-mountaintop-removal/ecology/.

Garcia, C., A. Ballester, F. Gonzalez, and M.L. Blazquez. 2004. Pyrite behavior in a Tailings Pond. *Hydrometallurgy*.

Garwin, Rachel. 2015. Science Desk: How Sulfide-Ore Copper Mines Pollute. *Save the Boundary Waters*. www.savetheboundarywaters.org/updates/science-desk-how-sulfide-ore-copper-mines-pollute.

Good Neighbor Agreement. 2019. Good Neighbor Agreement. Northern Plains Resource Council. [accessed 12/1/2019]; https://northernplains.org/issues/good-neighbor-agreement/

Hernández, A. J., and J. Pastor. 2008. Relationship between Plant Biodiversity and Heavy Metal Bioavailability in Grasslands Overlying an Abandoned Mine. Environ Geochem Health. 30:127–133.

How Can Mining Become More Environmentally Sustainable? 2018.

Green Directory: The South African Directory for Green Living. www.sa-green-info.co.za/portal/article/1633/how-can-mining-become-more-environmentally-sustainable.

Koning, A. D., R. Kleijn, G. Huppes, B. Sprecher, G. V. Engelen, and A. Tukker. 2018. Metal supply constraints for a low-carbon economy? Resources, Conservation and Recycling 129:202–208.

Laner, David, and Helmut Rechberger. Material Flow Analysis. SpringerLink, Springer, Dordrecht, 1 Jan. 1970, link.springer.com/chapter/10.1007/978-94-017-7610-3_7.

McCoy, S. 2019. Pebble Project EIS. U.S. Army Corps of Engineers. U.S. Army Corps of Engineers. Anchorage, Alaska, USA.

Mining 2020: Laws and Regulations: ICLG. Edited by Andrew Emrich, *International Comparative Legal Guides International Business Reports*, Global Legal Group, iclg.com/practice-areas/mining-laws-and-regulations.

Odell, S. D., A. Bebbington, and K. E. Frey. Mining and Climate Change: A Review and Framework for Analysis. 2018. The Extractive Industries and Society 5.1:201-14.

Our People. 2019. Bristol Bay Native Corporation, [accessed 12/1/2019]; https://www.bbnc.net/our-corporation/pebble-mine/

Pandey, Bhanu, et al. “Coal Mining Activities Change Plant Community Structure Due to Air Pollution and Soil Degradation.” *SpringerLink*, Springer US, 14 July 2014, link.springer.com/article/10.1007/s10646-014-1289-4.

Pebble Mine. 2019. Bristol Bay Native Corporation, Anchorage Alaska, USA. [accessed 12/1/2019]; https://www.bbnc.net/our-corporation/pebble-mine/

Pebble Mine Report. The Wild Salmon Center, TroutUnlimited. 2012. [accessed 12/1/2019]; https://www.wildsalmoncenter.org/resources/pebble-mine-report-main-page/

Pebble Partnership Ltd. 2019. Project Overview. Pebble Partnership Ltd. Anchorage, Alaska, USA. [accessed 12/1/2019]; https://pebblepartnership.com/project-overview

PwC. "Total Revenue of The Top Mining Companies Worldwide from 2002 to 2018 (in Billion U.S. Dollars)*." *Statista*, Statista Inc., 1 Jun 2019, https://www.statista.com/statistics/208715/total-revenue-of-the-top-mining-companies/

Ritchie, Hannah, and Max Roser. “Energy Production & Changing Energy Sources.” *Our World in Data*, 28 Mar. 2014, ourworldindata.org/energy-production-and-changing-energy-sources.

SaveBristolBay. 2017. Get The facts on Bristol Bay. [accessed 12/1/2019]; http://www.savebristolbay.org/thefacts

Stumm, Werner, and Fred Lee. *Oxygenation of Ferrous Iron*. Department of Sanitary Engineering, Harvard University, Cambridge, Mass., 31 Oct. 1960, www.gfredlee.com/SurfaceWQ/StummOxygenFerrous.pdf.

UN Press release. 2019, Feb 19. Call for strengthened governance to improve the social and environmental outcomes of mining. UN environment programme. [accessed 2019, November 6]. https://www.unenvironment.org/news-and-stories/press-release/call-strengthened-governance-improve-social-and-environmental

Woody, C., and S. O’Neal. 2012. *Effects of Copper on Fish and Aquatic Resources*. The Nature Conservancy. Anchorage, Alaska, USA. [accessed 12/1/2019]; http://www.pebblescience.org/copper-and-salmon.html

Zamzow, K. 2012. *Acid Rock Drainage and Metal Leaching at the Pebble Prospect*. Center for Science in Public Participation. Anchorage, Alaska, USA. [accessed 12/1/2019]; http://pebblescience.org/Pebble-Mine/acid_drainage.html

Chapter 6 References

---. 2019. What is the Farm Bill? Congressional Research Service. Retrieved: https://fas.org/sgp/crs/misc/RS22131.pdf

---. 2018. NRCS Montana Annual Report. Natural Resources Conservation Service. Retrieved: https://www.nrcs.usda.gov/wps/cmis_proxy/https/ecm.nrcs.usda.gov%3A443/fncmis/resources/WEBP/ContentStream/idd_30EA5567-0000-C21D-92FA-A54695A2A95E/0/NRCS-Report-2018-web.pdf.

---. 2017. Growth of Montana Pulse Acres. United States Department of Agriculture. Retrieved: https://agr.mt.gov/Portals/168/Documents/Pulse/2017_Pulse_Acres_Maps.pdf?ver=2017-11-30-102446-647&timestamp=1573096810690

---. 2017. Climate Change. USDA. Retrieved: https://www.ers.usda.gov/topics/natural-resources-environment/climate-change/

---. (n.d.) Cover Crop Presentations. Montana State Extension. Retrieved: http://landresources.montana.edu/soilfertility/covcroppres.html

Birch, A.N.E., G.S. Begg, and G.R. Squire. 2011. How agro-ecological research helps to address food security issues under new IPM and pesticide reduction policies for global crop production systems. *Journal of Experimental Botany*, 62(10), 3251-3261.

Blaauw, B.R., and R. Isaacs. 2014. Flower plantings increase wild bee abundance and the pollination services provided to a pollination-dependant crop. *Journal of Applied Ecology*. 51:890-898

Burkle, L.A., J.C. Marlin, and T.M. Knight. 2013. Plant-Pollinator Interactions over 120 Years: Loss of Species, Co-Occurrence, and Function. *Science*. 339(6127):1611-1615

Dubey, P. K., G.S. Singh, and P.C. Abhilash. 2019. Adaptive Agricultural Practices. *Springer Nature Switzerland*. 63-92

Ehler, L.E. 2006. Integrated pest management (IPM): definition, historical development and implementation, and the other IPM. *Pest Manag Sci*, 62, 787-789.

Ellis, J.D., J.D. Evans, and J. Pettis. 2010. Colony losses, managed colony population decline, and Colony Collapse Disorder in the United States. *Journal of Apicultural Research*. 49(1):134-136

Foley, Jonathan & Defries, Ruth & Asner, Gregory & Barford, Carol & Bonan, Gordon & Carpenter, Stephen & Chapin III, F Stuart & Coe, Michael & Daily, Gretchen & Gibbs, Holly & Helkowski, Joseph & Holloway, Tracey & Howard, Erica & Kucharik, Christopher & Monfreda, Chad & Patz, Jonathan & Prentice, Iain & Ramankutty, Navin & Snyder, Peter. (2005). Global Consequences of Land Use. *Science* (New York, N.Y.). 309. 570-4. 10.1126/science.1111772.

Garibaldi, L.A., I. Steffan-Dewenter, R. Winfree, M.A. Aizen, R. Bommarco, S.A. Cunningham, C. Kremen, L.G. Carvalheiro, L.D. Harder, O. Afik, I. Bartomeus, F. Benjamin, V. Boreux, D. Cariveau, N.P. Chacoff, J.H. Dudenhoffer, BM. Freitas, J. Ghazoul, S. Greenleaf, J. Hipolito, A. Holzschuh, B. Howlett, R. Isaacs, S.K. Javorek, C.M. Kennedy, K.M Krewenka, S. Krishnan, Y. Mandelik, M.M. Mayfield, I. Motzke, T. Munyuli, B.A.

Nault, M. Otieno, J. Peteren, G. Pisanty, S.G. Potts, R. Rader, T.H. Ricketts, M. Rundlof, C.L. Seymour, C. Schuepp, H. Szentgyorgyi, H. Taki, T. Tscharntke, C.H. Vergara, B.F. Viana, T.C. Wangerr, C. Westphal, N. Williams, and A.M. Kein. 2013. Wild Pollinators Enhance Fruit Set of Crops Regardless of Honey Bee Abundance. *Science*. 339:1608-1611

Georghiou, P.G., T. Saito. 1979. Pest Resistance to Pesticides. *Japan Cooperative Science Seminar on Pest Resistance to Pesticides: Challenges and Prospects*. [accessed 2019 Oct 25]; https://www.springer.com/gp/book/9781468444681

Gurr, G.M., S.D. Wratten, and J.M. Luna. 2003. Multi-function agricultural biodiversity: pest management and other benefits. *Basic and Applied Ecology*. 4(2), 107-116.

Horrigan, L., R. Lawrence, and P. Walker. 2002. How sustainable agriculture can address the environmental and human health harms of industrial agriculture. *Environmental Health Perspectives.* 110(5):445-456.

Jarchow, M.E, I. Kubiszewski, G.D. Larsen, G. Zdorkowski, R. Costanza, S.R. Gailans, N. Ohde, R. Dietzel, S. Kaplan, J. Neal, M.R. Petrehn, T. Gunther, S.N. D'Adamo, N. McCann, A. Larson, P. Damery, L. Gross, M. Merriman, J. Post, M. Sheradin, 'and' M. Liebman, 2012. The future of agriculture and society in Iowa: four scenarios. *International Journal of Agricultural Sustainability.* 10(1), 76-92.

Johnsen, D. B. 2009. Salmon, Science, and Reciprocity on the Northwest Coast. *Ecology and Society.* 14.

Karuppiah, V. , G.K. Sujayanad. 2012. Impact of Climate Change on Population Dynamics of Insect Pest. *World Journal of Agricultural Sciences*, 8(3), 240-246.

Kimmerer, R. W., F. K. Lake. 2001. The Role of Indigenous Burning in Land Management. *Journal of Forestry.* 99:36-41.

Kolbert, E., 2014. The Sixth Extinction: An Unnatural History. First edition. New York : Henry Holt and Company, 2014.

Kremen, C., N.M. Williams, and R.W. Thorp. 2002. Crop pollination from native bees at risk from agricultural intensification. *PNAS*. 99(26):16812-16816

Lenssen, A.W., G.D. Johnson, and G.R. Carlson. 2007. Cropping sequence and tillage system influences annual crop production and water use in semiarid Montana, USA. *Field Crops Research*. 100:32-43

Leong, M., L.C. Ponisio, C. Kremen, R.W. Thorp, and G.K. Roderick. 2015. Temporal dynamics influenced by global change: bee community phenology in urban, agricultural, and natural landscapes. *Global Change Biology*. 22:1046-1053

Lockeretz, W., and M.D. Anderson. 1990. Farmers' role in sustainable agriculture research. *American Journal of Alternative Agriculture*. 5(4):178-182

Mallinger, R.E., J. Bradshaw, A.J. Varenhorst, and J.R. Prasifka. 2019. Native Solitary Bees Provide Economically Significant Pollination Services to Confection Sunflowers (Helanthus annus L.) (Asterales: Asteraceae) Grown Across the Northern Great Plains. *Journal of Economic Entomology*. 112(1):40-48

McGregor, S.E. 1976. Insect Pollination of Cultivated Crop Plants. *U.S.D.A. Agriculture Handbook.* 496

Memmott, J., N.M. Waser, and M.V. Price. 2004. Tolerance of pollination networks to species extinctions. *Proceedings of the Royal Society London*. 271:2605-2611

Morandin, L.A., and C. Kremen. 2013. Hedgerow restoration promotes pollinator populations and exports native bees to adjacent fields. *Ecological Applications*. 23(4):829-839

Ollerton, J., R. Winfree, and S. Tarrant. 2011. How many flowering plants are pollinated by animals? *Oikos*. 120:321-326
Parry, R. 1998. Agricultural Phosphorus and Water Quality: A U.S. Environmental Protection Agency Perspective. *Journal of Environmental Quality.* 27(2):258-261.
Plantinga, A. J. 1996. The Effect of Agricultural Policies on Land Use and Environmental Quality. *American Journal of Agricultural Economics*. 78(4):1082-1091.
Porter, J.H., M.L Parry, and T.R. Carter. 1991. The potential effects of climate change on agricultural insect pests. *Agriculture and Forest Meteorology*. 57(1-3):221-240.
Ritchie, H., and M. Roser. 2019. Land Use. [accessed 2019 Oct 29]: https://ourworldindata.org/land-use.html
Roberts, P. A., and M.L. Flint. 1988. Using crop diversity to manage pest problems: Some California Examples. *American Journal of Alternative Agriculture*. 3(4):163-167
Severin, H., S. Artru, D. Bredart, L. Lassois, F. Francis, E. Haubruge, S. Garre, P.M. Stassart, M. Dufrene, A. Monty, and F. Boeraeve. 2016. Towards sustainable food systems: the concept of agroecology and how it questions current research practices. A review. Biotechnol. *Agron. Soc. Environ.* 20(S1):215-224
Steffan-Dewenter, I., U. Munzeberg, C. Burger, C. Thies, and T. Tscharntke. 2002. Scale-Dependent effects of Landscape Context on Three Pollinator Guilds. *Ecology*. 83(5):1421-1432
Steffan-Dewenter, I., T. Tscharntke. 1999. Effects of habitat isolation on pollinator communities and seed set. *Oecologia*. 121:432-440
Williams, N.M., K.L. Ward, N. Pope, R. Isaacs, J. Wilson, E.A. May, J. Ellis, J. Daniels, A. Pence, K. Ullmann, and J. Peters. 2015. Native wildflower plantings support wild bee abundance and diversity in agricultural landscapes across the United States. *Ecological Applications*. 25(8):2119-2131
Xu, Q. 2014. The study of agricultural non-point source pollution control policy system. *Masters Thesis, Michigan Technological University, 2014.* [accessed 2019 Oct 25]; https://pdfs.semanticscholar.org/59e7/b6562a6374570cec14d3de939b3c20e087e9.pdf

Chapter 7 References

American Soybean Association (ASA). 2018. SoyStats: A Reference Guide to Soybean Facts and Figures. American Soybean Association.
Arcury, T., and L. Quandt. 2003. Pesticides at work and home, exposure of migrant farmworkers, The Lancet, 362: 2021.
Battaglin, W.A., M.T. Meyer, K.M. Kuivila, and J.E. Dietze. 2014. Glyphosate and its degradation product AMPA occur frequently and widely in U.S. soils, surface water, groundwater, and precipitation. Journal of the American Water Resources Association, v. 50, no. 2, p. 275-290.
Benbrook, C. 2016. Trends in Glyphosate Herbicide Use in the United States and Globally. Environmental Sciences Europe, vol. 28, no. 1, ser. 3.
Boerboom, T., K. Chris, and M. Owen. 2016. Facts about Glyphosate- Resistant Weeds. Purdue Extension Office.

Borggaard, O.K., and A. Gimsing. 2007. Fate of Glyphosate in Soil and the Possibility of Leaching to Ground and Surface Waters: a Review. Pest Management Science vol. 64, no. 4, 2008, pp. 441–456.

Bunge, J. 2019. Despite Rulings, Farmers Remain Loyal to Bayer's Roundup. [accessed 2019 Nov 25]; wsj.com/articles/despite-rulings-farmers-remain-loyal-to-roundup-11553175429

Cederlund M., and S. Harald. 2017. Effects of Spray Drift of Glyphosate on Non-Target Terrestrial Plants. Society of Environmental Toxicology and Chemistry vol. 36, no. 11.

EPSP Synthase Inhibitors, Herbicide Symptoms. N.d. University of California [accessed 2019 Oct 18]; herbicidesymptoms.ipm.ucanr.edu/MOA/EPSP_synthase_inhibitors/.

Exposed and Ignored: How pesticides are endangering our nation's farmworkers. 2013. Farmworker Justice. Washington DC, United States. [accessed 2019 Nov 25]; https://www.farmworkerjustice.org/press#location-47

Giesey J. P., S. Dobson, and K.R. Solomon. 2000. Ecotoxicological risk assessment for Roundup herbicide. Rev. Environ. Contam. Toxicol. 167: 35-120.

Glyphosate Product Label. 1998. Environmental Protection Agency. [accessed 2019 Sept 30]; www3.epa.gov/pesticides/chem_search/ppls/091543-00001-20160621.pdf.

Herbicide-Resistant Weeds by Site of Action. 2019. National Survey of Herbicide Resistant Weeds. [accessed 2019 Dec 2]; www.weedscience.org/Summary/MOA.aspx?MOAID=12.

Herbicide Resistance. N.d. Weed Science Society of America. [accessed 2019 Oct 5]; wssa.net/wssa/weed/resistance/.

La Cecilia P., M. Daniele, and F. Maggi. 2018. Analysis of Glyphosate Degradation in a Soil Microcosm. Environmental Pollution vol. 233.

Machado-Neto V., G. Joaquim. 2015. Safety Measures for Handlers/Workers against Herbicide Intoxication Risk. IntechOpen.

Manning S., M. Steven, and J. Miller. 200.1 USDA Forest Service: Invasive Plant Control. USDA Forest Service: Invasive Plant Control.

Meyer, D.E. and C. Cederberg. 2010. Pesticide Use and Glyphosate- Resistant Weeds. SIK-Rapport.

Mink, P. J., S. Jack, K. Bonnielin, and K. Jessica, I. L. 2011. Epidemiologic studies of glyphosate and cancer: A review. Regulatory Toxicology and Pharmacology. **63**: 440-452.

National Agricultural Aviation Association (NAAA). N.d. Aerial Application Industry. National Agricultural Aviation Association, Naylor Association Management Software.

National Forest Service (NFS). 2012. Aerial Spray Guidelines. United States Department of Agriculture.

Peltzer T., R. Sally, and A. Douglas. 2019. Herbicide Resistance. Agriculture and Food, Australian Department of Primary Industries & Regional Development.

Pérez, G.L. 2007. Effects of the herbicide Roundup on freshwater microbial communities: a mesocosm study. Ecological Applications vol. 17 pp 2310-22.

Price A. 2018. New Study Shows Roundup Kills Bees. Sierra Club, USA. [accessed 2019 Nov 25]; https://www.sierraclub.org/sierra/new-study-shows-roundup-kills-bees

Reducing Pesticide Drift. Environmental Protection Agency. 2019. Environmental Protection Agency (EPA). [accessed 2019 Sept 30]; www.epa.gov/reducing-pesticide-drift.

Salvatore, A. L., A. Bradman, R. Castorina, J. Camacho, J. López, D. Barr, J. Snyder, N. Jewell, and B. Eskenazi. 2008. Occupational behaviors and farmworkers' pesticide exposure: Findings from a study in Monterey County, California. American Journal of Industrial Medicine, **51**: 782-794.

Silva, V., L. Montanarella, A. Jones, O. Fernández-Ugalde, H. Mol, C. Ritsema, and V. Geissen. 2018. Distribution of Glyphosate and Aminomethylphosphonic Acid (AMPA) in Agricultural Topsoils of the European Union. Science of the Total Environment vol. 621, 2018.

Springer, P. 2019. Roundup is a popular herbicide, but thousands of lawsuits blame it for causing cancer.[accessed 2019 Nov 25]; https://www.agweek.com/business/agriculture/4676806-roundup-popular-herbicide-thousands-lawsuits-blame-it-causing-cancer.

Tapu, C. 2013. The Pioneers of the Green Revolution as Forerunners of Today's Ecological and Biotechnological Revolutions. Scientific Papers Series: Management, Economic Engineering in Agriculture and Rural Development vol. 13, no. 1, pp. 427–430.

Tessier, M.C. and G. D. Leroux. 2010. Banded Herbicide Application. Quebec Reference Center for Agriculture and Agri-Food.

Timmons, F.L. 2005. A History of Weed Control in the United States and Canada. Weed Science vol. 53, pp. 748–761.

United States Department of Agriculture (USDA). 2017. The History and Current Status of Glyphosate. Pest Management Science vol. 74, no. 5.

Yenduri, A. and S. Onkar. 2019. Herbicides Market by Type (Synthetic Herbicide and Bioherbicide), Mode of Action (Selective and Non-selective), and Crop Type (Corn, Cotton, Soybean, Wheat, and Others): Global Opportunity Analysis and Industry Forecast, 2018 - 2025. Allied Market Research.

Chapter 8 References

2015. Global Wind Report. Global Wind Energy Council.

2016. U.S. number one in the world in wind energy production. American Wind Energy Association.

2017. US wind O&M costs estimated at $48,000/MW; Falling costs create new industrial uses: IEA. New Energy Update.

2019. Understanding the Decibel. NetWell Noise Control.Azar, C., K. Lindgren, M. Obersteiner, K. Riahi, D. van Vuuren, K. Den Elzen, K. Möllersten, and E. Larson. 2010. The feasibility of low CO2 concentration targets and the role of bio-energy with carbon capture and storage (BECCS). Climatic Change **100**:195-202.

Aranguren, B. et al. 27 Feb. 2018. Wooden Tools and Fire Technology in the Early Neanderthal Site of Poggetti Vecchi (Italy). National Academy of Sciences. [accessed 2019 Nov. 15]; www.pnas.org/content/115/9/2054.

Assessment of Disposal Options for DOE-Managed High-Level Radioactive Waste and Spent Nuclear Fuel, October 2014, US DOE.

Benson, T. 2007, January 19. Morales says Bolivia to nationalize mining sector. Thomson Reuters. https://www.reuters.com/article/us-bolivia-mining-nationalization/morales-says-bolivia-to-nationalize-mining-sector-idUSN1918440820070119.

Biello, D. 2008, August 4. China's Big Push for Renewable Energy. [accessed 2019 Oct 24]: https://www.scientificamerican.com/article/chinas-big-push-for-renewable-energy/
Biofuels Explained. 23 Oct. 2019. U.S. Energy Information Administration (EIA). [accessed 2019 Nov. 15]; www.eia.gov/energyexplained/biofuels/.
Biofuels Issues and Trends. 15 Oct. 2012. Energy Information Administration. [accessed 2019 Nov. 19]; www.eia.gov/biofuels/issuestrends/.
Boyle, G.. 2003. Energy systems and sustainability. New York: Oxford Press.
Cha, A. E. 2008, March 9. Solar Energy Firms Leave Waste Behind in China. Washington Post Foreign Service. [accessed 2019 Nov 1]: http://www.washingtonpost.com/wp-dyn/content/article/2008/03/08/AR2008030802595.html
Ciolkosz, D. 9 June 2016. Using Biodiesel Fuel in Your Engine. Penn State University. [accessed 2019 Nov. 29] extension.psu.edu/using-biodiesel-fuel-in-your-engine.
Cook, T., & Perrin, J. 2016, March 15. Unconventional Oil and Gas Development: Key Environmental and Public Health Requirements. EIA Independent Statistics and Analysis.
Cook, T., & Perrin, J. 2016, March 5. U.S. Hydraulically fractured wells provide two-thirds of U.S. natural gas production. EIA Independent Statistics and Analysis.
Davis, C. 2017. Fracking and environmental protection: An analysis of U.S. state policies. The Extractive Industries and Society 4:63–68.
Deaton, A. 2013. The great escape : health, wealth, and the origins of inequality. Princeton Univ. Press, Princeton, Nj.
Demirbus, A. 2 Mar. 2009. Combustion Efficiency Impacts of Biofuels. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects. [accessed 2019 Nov. 16]; www.tandfonline.com/doi/abs/10.1080/15567030701743718?journalCode=ueso20.
Devries, T., M. Holzer, and F. Primeau. 2017. Recent increase in oceanic carbon uptake driven by weaker upper-ocean overturning. Nature **542**:215-218.
Dinçer, H., S. Yüksel, and Z. Adalı. 2017. Identifying Causality Relationship between Energy Consumption and Economic Growth in Developed Countries. International Business and Accounting Research Journal 1:71.
Eckstein, D., M.-L. Hutfils, and M. Winges. 2018. Global Climate Risk Index 2019. Germanwatch.
Eisler, R. 2013. The Fukushima 2011 Disaster. CRC Press, Boca Raton, FL.
EIA. 2016. Renewable energy explained - U.S. Energy Information Administration (EIA).
EIA. 2019. Each Country's Share of CO2 Emissions.
Energy, O. o. E. E. a. R. Wind Vision. Department of Energy.
Energy , R. Saidur 2011, Slattery 2011, 2015, Wang 2015, 2016, 2017, 2019, Wilkerson 2019
Ethical and Social Issues. 2 Apr. 2014. U.S. National Library of Medicine. [accessed 2019 Nov. 19] www.ncbi.nlm.nih.gov/books/NBK196458/.
Fact 7: Water & Biofuels. 2014. UNESCO. [accessed 2019 Nov. 29] www.unesco.org/new/en/natural-sciences/environment/water/wwap/facts-and-figures/all-facts-wwdr3/fact-7-water-biofuel/.
FAQ-Output. National Wind Watch.
Folger, P. 9 Nov. 2017. Drought in the United States: Causes and Current Understanding. Congressional Research Service. [accessed 2019 Dec. 1] fas.org/sgp/crs/misc/R43407.pdf.

Food Waste to Biofuels. 28 Feb. 2019. Nordic Energy. [accessed 2019 Nov. 19] www.nordicenergy.org/wp-content/uploads/2019/04/Food-Waste-to-Biofuels_FINAL.pdf.

Friedlingstein, P., R. M. Andrew, J. Rogelj, G. P. Peters, J. Canadell, R. Knutti, G. Luderer, M. Raupach, M. Schaeffer, D. van Vuuren, and C. Le Quere. 2014. Persistent growth of CO2 emissions and implications for reaching climate targets. Nat. Geosci. **7**:709-715.

Friedman, S. M. 1987. Reporting on Radiation: A Content Analysis of Chernobyl Coverage. Journal of Communication 37:58-67.

Friedman, S. M. 2011. Three Mile Island, Chernobyl, and Fukushima: An analysis of traditional and new media coverage of nuclear accidents and radiation. Bulletin of the Atomic Scientists 67:55-65.

Gabbatiss, J. (n.d.). Solar power is cheaper than grid electricity in China. [accessed 2019 Oct 18]: https://www.weforum.org/agenda/2019/08/solar-now-cheaper-than-grid-electricity-in-every-chinese-city-study-finds/

Gardner, J., C. Manno, D. Bakker, V. Peck, and G. Tarling. 2018. Southern Ocean pteropods at risk from ocean warming and acidification. Mar Biol **165**:1-12.Gattuso, J.-P., and L. Hansson. 2011. Ocean acidification. Oxford England New York : Oxford University Press, Oxford [England]New York.

Gent, E. 20 June 2017. New Biofuel Could Work in Regular Diesel Engines. Live Science. [accessed 2019 Nov. 29] www.scientificamerican.com/article/new-biofuel-could-work-in-regular-diesel-engines/.

Goldenstein, C. 15 July 2019. Advanced Combustion Engines. Stanford University. [accessed 2019 Nov. 15]; large.stanford.edu/courses/2011/ph240/goldenstein2/.

Harris, B. (n.d.). What is a sovereign wealth fund? https://www.weforum.org/agenda/2017/10/what-you-need-to-know-about-sovereign-wealth-funds/.

Hernandez, R. R., Easter, S. B., Murphy-Mariscal, M. L., Maestre, F. T., Tavassoli, M., Allen, E. B., … Allen, M. F. 2013, September 28. Environmental impacts of utility-scale solar energy. [accessed 2019 Nov 1]: https://www.sciencedirect.com/science/article/pii/S1364032113005819.

Hindmarsh, R. 2013. Nuclear Disaster at Fukushima Daiichi. Routledge, New York, NY.

History of the Alaska Permanent Fund. (n.d.). . https://apfc.org/who-we-are/history-of-the-alaska-permanent-fund/.

Hoekstra, A. Y., and T. O. Wiedmann. 2014. Humanity’s unsustainable environmental footprint. Science. The American Association for the Advancement of Science *344* (6188), 1114-1117.

Hore-Lacy, I. 2012. Nuclear Energy in the 21st Century. 3rd edition. World Nuclear University Press, London, United Kingdom.

How Biofuel Is Made. 22 Aug. 2017. Arcadia Power. [accessed 2019 Nov. 15]; blog.arcadiapower.com/how-biofuel-is-made/.

How much do wind turbines cost? Windustry.

Hutchins, W. 2015, May 15. Stop using DNR public timber sales for school funding. The Seattle Times Company. https://www.seattletimes.com/opinion/stop-using-dnr-public-timber-sales-for-school-funding/.

Imtihani, N., and Y. Mariko. 2013. Media coverage of Fukushima nuclear power station accident 2011 (A case study of NHK and BBC WORLD TV stations). Procedia Environmental Sciences 17:938-946.

Jackson, R. 2018, November 28. Global Climate Change: Effects.

J. J. Gómez Cadenas. 2012. The Nuclear Environmentalist. Copernicus Books.

Jones, N. 2013. RISING TIDE. Nature **501**:300-302.

Kepplinger, H.M. and R. Lemke. 2016. Instrumentalizing Fukushima: Comparing Media Coverage of Fukushima in Germany, France, the United Kingdom, and Switzerland. Political Communication 33:351-373.

Maddison. 2017. Global Carbon Project (GCP). Global Carbon Project (GCP).

Marland, G., T. A. Boden, and R. J. Andres. 1985. Global, Regional, and National Fossil Fuel CO2 Emissions. Environmental System Science Data Infrastructure for a Virtual Ecosystem.

McLamb, E. 12 Oct. 2011. The Secret World of Energy. Ecology Global Network. [accessed 2019 Nov. 15]; www.ecology.com/2010/09/15/secret-world-energy/.

Medvedev, Z. A. 1990. The Legacy of Chernobyl. W.W. Norton & Company, Inc., New York, NY.

Meinshausen, M., S. Smith, K. Calvin, J. Daniel, M. Kainuma, J. F. Lamarque, K. Matsumoto, S. Montzka, S. Raper, K. Riahi, A. Thomson, G. Velders, and D. P. Vuuren. 2011. The RCP greenhouse gas concentrations and their extensions from 1765 to 2300. Climatic Change **109**:213-241.

Melsted, O. Pallua, I. 17 Dec. 2018. The Historical Transition from Coal to Hydrocarbons: Previous Explanations and the Need for an Integrative Perspective. Canadian Journal of History. [accessed 2019 Nov. 15]; www.utpjournals.press/doi/full/10.3138/cjh.ach.53.3.03#_i6.

Mulvaney, D. 2014, November 13. Solar Energy Isn't Always as Green as You Think. Retrieved from https://spectrum.ieee.org/green-tech/solar/solar-energy-isnt-always-as-green-as-you-think.

National Interagency Fire Center, a. 2018. National Interagency Fire Center.*in* c. Federal Depository Library Program and d. United States. Government Publishing Office, editors. NIFC. Boise, ID : National Interagency Fire Center.

National Petroleum Council, 2011 September 15. Prudent Development: Realizing the Potential of North America's Abundant Natural Gas and Oil Resources. [accessed 2019 Nov 1]: https://www.npc.org/

Natural Gas Explained. 10 July 2019. U.S. Energy Information Administration (EIA). [accessed 2019 Nov. 15]; www.eia.gov/energyexplained/natural-gas/use-of-natural-gas.php.

Nickerson, C. Borchers. A. 1 Mar. 2012. How Is Land in the United States Used? A Focus on Agricultural Land. USDA. [accessed 2019 Nov. 29] www.ers.usda.gov/amber-waves/2012/march/data-feature-how-is-land-used/.

Nunez, C. 15 July 2019. Biofuels, Explained. National Geographic. [accessed 2019 Nov. 16]; www.nationalgeographic.com/environment/global-warming/biofuel/#close.

Oil: Crude and Petroleum Products Explained. 3 Oct. 2019. U.S. Energy Information Administration (EIA). [accessed 2019 Nov. 15]; www.eia.gov/energyexplained/oil-and-petroleum-products/use-of-oil.php.

Pike, J. (n.d.). Military. https://www.globalsecurity.org/military/world/bolivia/economy-mining-structure.htm.
Prashad, V. 2019, November 12. After Morales Ousted in Coup, the Lithium Question Looms Large in Bolivia. https://www.commondreams.org/views/2019/11/12/after-morales-ousted-coup-lithium-question-looms-large-bolivia.
Prayaga, P., J. Rolfe, and N. Stoeckl. 2010. The value of recreational fishing in the Great Barrier Reef, Australia: A pooled revealed preference and contingent behaviour model. Marine Policy **34**:244-251.
Public vs Private: A National Overview of Water Systems. 2016, October 19. . http://efc.web.unc.edu/2016/10/19/public-vs-private-a-national-overview-of-water-systems/.
R. Saidur, N. R., M. Islam, K. Solangi. 2011. Environmental impact of wind energy. Renewable and Sustainable energy reviews 15:2423-2430.
Radeloff, V., R. Hammer, S. Stewart, J. Fried, S. S. Holcomb, and J. McKeefry. 2005. The wildland-urban interface in the United States. Ecol. Appl. **15**:799-805.
Schauer, D. 2009. Ionizing radiation exposure of the population of the United States. National Council on Radiation Protection and Measurements.
Scheer, R. Moss, D. 12 Oct. 2013. Food Waste to Energy. EarthTalk. [accessed 2019 Nov. 19] www.scientificamerican.com/article/food-waste-to-energy/.
Schneider, E., B. Carlsen, E. Tavrides, C. van der Hoeven, and U. Phathanapirom. 2013. Measures of the environmental footprint of the front end of the nuclear fuel cycle. Energy Economics *40*, 898-910.
Shubbak, M. H. 2018, October 15. The technological system of production and innovation: The case of photovoltaic technology in China. [accessed 2019 Oct 25]: https://www.sciencedirect.com/science/article/pii/S004873331830235X?via=ihub.
Slattery, M. 2011. State and local economic impacts from wind energy projects: Texas case study. Energy Policy 39:7930-7940.
Smith, J., and A, Beresford. 2005. Chernobyl: Catastrophe and Consequences. Praxis Publishing, Chichester, UK.
Solsvik, T. 2019, October 25. Norway wealth fund grows to record 10 trillion crowns. Thomson Reuters. https://www.reuters.com/article/us-norway-swf-record-idUSKBN1X41AO.
Sources of Greenhouse Gas Emissions. 13 Sept. 2019. Environmental Protection Agency. [accessed 2019 Nov. 15]; www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions.
Sundlee, R. 2019, September 5. Alaska's universal basic income problem. Vox. https://www.vox.com/future-perfect/2019/9/5/20849020/alaska-permanent-fund-universal-basic-income.
The State of Public Water in the United States. 2016, February 29. . https://www.foodandwaterwatch.org/insight/state-public-water-united-states.
The World Bank. 2018. Dominica | Data. https://data.worldbank.org/country/dominica.
Trina Solar Company. c2012-2019. [accessed 2019 Nov 5]: https://www.trinasolar.com/us
UNDP. 2000. Human Development Index (HDI) | Human Development Reports.
Van Oppen, M. J. H., J. M. Lough, J. M. Lough, M. J. H. Van Oppen, and SpringerLink. 2009. Coral Bleaching Patterns, Processes, Causes and Consequences. Berlin, Heidelberg : Springer Berlin Heidelberg : Imprint: Springer, Berlin.

Veblen, T. T., W. L. Baker, G. Montenegro, and T. W. Swetnam. 2003. Fire and Climatic Change in Temperate Ecosystems of the Western Americas. New York, NY : Springer New York : Imprint: Springer.
Vermeer, M., and S. Rahmstorf. 2009. Global sea level linked to global temperature. Proceedings of the National Academy of Sciences of the United States of America **106**:21527-21532.
Waltar, A. E. 1995. America The Powerless. Cogito Books, Madison, Wisconsin.
Wang, S. 2015. Impacts of wind energy on environment: a review. Renewable and Sustainable energy reviews 49:437-443.
Water Implications of Biofuels Production in the United States. 2008. National Academies Press. [accessed 2019 Nov. 19] https://ebookcentral.proquest.com/lib/montana/detail.action?docID=3564143.
Wicklund, R. A., J. C. Ogden, and S. United. 1988. Mass bleaching of coral reefs in the Caribbean: a research strategy. Rockville MD: National Oceanic and Atmospheric Administration, Oceanic and Atmospheric Research, Office of Undersea Research.
Wilkerson, J. 2019. Future Widespread Water Shortage Likely in U.S. Harvard University.Wu, Z., Hou, A., Chang, C., Huang, X., Shi, D., & Wang, Z. 2014, August 7. Environmental impacts of large-scale CSP plants in northwestern China.
Willeit, M., A. Ganopolski, R. Calov, and V. Brovkin. 2019. Mid-Pleistocene transition in glacial cycles explained by declining CO 2 and regolith removal. Science Advances **5**.
Wilson, P. D. 1996. The Nuclear Fuel Cycle, Oxford University Press.
WNA. 2013. Storage and Disposal Options. Radioactive Waste Management Appendix 2; World Nuclear Association.
World Economic Outlook Database April 2009 -- WEO Groups and Aggregates Information. 2009.
Wright, M. 2019, March 6. Group blocks timber harvest southeast of Bozeman. https://www.bozemandailychronicle.com/news/environment/group-blocks-timber-harvest-southeast-of-bozeman/article_6d5695e5-3e81-589b-a368-c2d9bd0154fd.html.
Yang, X. J., Hu, H., Tan, T., & Li, J. 2016, October 4. China's renewable energy goals by 2050. [accessed 2019 Nov 8]: https://www.sciencedirect.com/science/article/pii/S221146451630152X?via=ihub
Xiang, H., and Y. Zhu. 2011. The Ethics Issues of Nuclear Energy: Hard Lessons Learned from Chernobyl and Fukushima. Online Journal of Health Ethics 7, Issue 2, Article 6.
Zafrilla, J. E., M. A. Cadarso, F. Monsalve, and C. de la Rúa. 2014. How Carbon-Friendly Is Nuclear Energy? A Hybrid MRIO-LCA Model of a Spanish Facility. Environmental Science & Technology *48* (24), 14103-14111.

Chapter 9 References

Asmar, B. N., and P. Ergenzinger. 2002. Environmental Effects of The Dead Sea-Red Sea Canal. International Journal of Environmental Studies 59:647–664.
Asmar, B. N. 2003. The Science and Politics of the Dead Sea: Red Sea Canal or Pipeline. The Journal of Environment & Development 12:325–339.
Baguma, D., S. Aljunid, J. Hashim, H. Jung, and L.Willibald. 2012. Rainwater and Health in Developing Countries: A Case Study on Uganda. United Nations University

Baines, L. 2014. The Fight for Water. Project Based Writing in Science. Sense Publishers. 41:81-90.
Bakker, K. 2007. The “commons” versus the “commodity”: Alter-globalization, anti-privatization and the human right to water in the global south. Antipode 39:430–455.
Beyth, M. 2007. The Red Sea and the Mediterranean–Dead Sea canal project. Desalination 214:365–371.
Bhateria, R. and D. Jain. 2016. Water quality assessment of lake water: a review. Sustainable Water Resources Management. 2:161-173.
Black, M. 2016 The Atlas of Water 3rd edition. University of California Press
Boundary Descriptions and Names of Regions, Subregions, Accounting Units and Cataloging Units. U.S. Geological Survey. [accessed 2019, Oct 29]; https://water.usgs.gov/GIS/huc_name.html.
Bulloch, J., and A. Darwish. 2017. Water Wars: Coming Conflicts in the Middle East. [accessed 2019 Oct 30]; https://www.mepc.org/water-wars-coming-conflicts-middle-east.
Cable, R.N., D. Beletsky, R. Beletsky, K. Wigginton, B. Locke, and M Duhaime. 2017. Distribution and modeled transport of plastic pollution in the great lakes, the world's largest freshwater resource. Frontiers in Environmental Science. 5:45. doi:10.3389/fenvs.2017.00045
Cantor, A.C., Owen, D.O., Harter, T.H., Nylen, N.G.N., and Kiparsky, M.K. 2018. Navigating Groundwater-Surface Water Interactions Under the Sustainable Groundwater Management Act. Center for Law, Energy and the Environment, UC Berkeley School of Law. Pg. 1-44.
Capalbo, S., S. D. Eigenbrode, P. Glick, J. Littel, R. Raymondi, and S. Reeder. 2014. Nothwest. National Climate Assessment. [accessed 2019, Oct 29]; https://nca2014.globalchange.gov/report/regions/northwest.
Carrington, D. 2017. Plastic fibres found in tap water around the world. The Guardian. [accessed 2019 Oct 02]; https://www.theguardian.com/environment/2017/sep/06/plastic-fibres-found-tap-water-around-world-study-reveals.
De Pinto, J.V., T. Young, and L. McIlroy. 1986. Great lakes water quality improvement. Environmental Science and Technology. [accessed 2019 Nov 10]; https://pubs.acs.org/doi/pdf/10.1021/es00150a001.
Dieter, C.A., Maupin, M.A., Caldwell, R.R., Harris, M.A., Ivahnenko, T.I., Lovelace, J.K., Barber, N.L., and Linsey, K.S. 2018. Estimated use of water in the United States in 2015. U.S. Geological Survey Circular. 1441:65-73.
Filmer-Wilson, E. 2005. The Human Rights-Based Approach to Development: The Right to Water. Netherlands Quarterly of Human Rights 23:213–241.
Garfin, G., G. Franco, H. Blanco, A. Comrie, P. Gonzalez, T. Piechota, R. Smyth, R. Waskom, J. M. Melillo, T.C. Richmond, and G. W. Yohe. 2014. Southwest Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program. 462-486. doi:10.7930/J08G8HMN.
Gavrieli, I., A. Bein, and A. Oren. 2005. The expected impact of the “Peace Conduit” project (the Red Sea - Dead Sea pipeline) on the Dead Sea. Mitigation and Adaptation Strategies for Global Change 10:759–777.
Gleick, P. H. 1998. The human right to water. Water policy 1:487–503.

Hafez, A., and S. El-Manharawy. 2003. Economics of seawater RO desalination in the Red Sea region, Egypt. Part 1. A case study. Desalination 153:335–347.
Hoepner, T., and S. Lattemann. 2003. Chemical impacts from seawater desalination plants — a case study of the northern Red Sea. Desalination 152:133–140.
Huang, S., Q. Huang, J. Chang, and G. Leng. 2015. Linkages between hydrological drought, climate indices and human activities: a case study in the Columbia River Basin. International Journal of Climatology 36:280-290.
Hussein, M. A. 2011. Impacts of Water Scarcity on the Social Welfare of Citizens in the Middle East. Washington, DC: Middle East Institute 1.
Jennewein, J. S., and K. W. Jones. 2016. Examining ‘willingness to participate’ in community-based water resource management in a transboundary conservation area in Central America. Water Policy 18:1334-1352.
Kendall, L.K. 2018. Bozeman Area Again Ranked Fastest Growing of its Size in the Nation. Bozeman Daily Chronicle. [accessed 2019 Nov 19th]; https://www.bozemandailychronicle.com/news/bozeman-area-again-ranked-fastest-growing-of-its-size-in/article_881f7994-a3d7-5f68-b85c-5875d2c0749a.html
Kliot, N. 2005. Water Resources and Conflict in the Middle East. Routledge.
Kunkel, E.K., L.E. Stevens, S.E. Stevens, L. Sun, E. Janssen, D. Wu-ebbles, K. Redmond, and J.G. Dobson. 2013. Regional Climate Trends and Scenarios for the U.S. National Climate Assessment. National Oceanic and Atmospheric Association. [accessed 2019 Oct 29]; https://www.nesdis.noaa.gov/sites/default/files/asset/document/NOAA_NESDIS_Tech_Report_142-6-Climate_of_the_Northwest_U.S.pdf.
Kummu, M., P. J. Ward, H. D. Moel, and O. Varis. 2010. Is physical water scarcity a new phenomenon? Global assessment of water shortage over the last two millennia. Environmental Research Letters 5:034006.
Littel, J.S., M. McGuire Elsner, L.C. Whitely Binder, and A.K. Snover. 2009. The Washington Climate Change Impacts Assessment: Evaluating Washington’s Future in a Changing Climate. University of Washington.
Liu, J., A. Dorideren, J. Fu, X. Lei, and D. Macer. 2011. Water Ethics and Water Resource Management. Water Ethics and Water Resource Management.
Metesh, J.M. 2011. Hydrogeology Related to Exempt Wells in Montana: A Report to the 2010-2012 Water Policy Interim Committee of the Montana Legislature. Montana Bureau of Mines and Geology. Pg. 1-20.
Microplastics in the great lakes: becoming benthic. 2019. Geological Society of America. [accessed 2019 Nov 03]; https://phys.org/news/2019-09-microplastics-great-lakes-benthic.html.
Montana Groundwater Information Center. 2019. Montana Bureau of Mines and Geology. [accessed 2019 Nov 16]. https://mbmggwic.mtech.edu/
Morales, L. 2019. Many Native Americans Can't Get Clean Water, Report Finds. National Public Radio. [accessed 2019 Nov 16]; https://www.npr.org/2019/11/18/779821510/
Mote, P.W., and D. Sharp. 2016. Declining mountain snowpack in Western North America. B. Am. Meteorol. Soc. 86(1):39–49.
Moursi, H., D. Kim, and J. J. Kaluarachchi. 2017. A probabilistic assessment of agricultural water scarcity in a semi-arid and snowmelt-dominated river basin under climate change. Agricultural Water Management 193:142-152.

Niemi, E.N., S.R. Reich, C.N. Nuculae, M.B. Buckley. 2017. Irrigation in Montana: A Program Overview and Economic Analysis. Montana Annual Bulletin. ECONorthwest. Pg. 1-104.

Pacific Northwest Hydropower for the 21st Century Power Grid.2019. Northwest Power and Conservation Council. [accessed 2019, Oct 29]; https://www.nwcouncil.org/energy/energy-topics/hydropower

Principles of Water Ethics. (n.d.). https://www.humansandnature.org/principles-of-water-ethics.

Qtaishat, M. R., and F. Banat. 2013. Desalination by solar powered membrane distillation systems. Desalination 308:186–197.

Reduce Hot Water Use for Energy Savings. n.d. US Department of Energy. [accessed 2019 Oct 16]; https://www.energy.gov/energysaver/water-heating/reduce-hot-water-use-energy-savings

Richter, A. and Kolmes S. 2005. Maximum Temperature Limits for Chinook, Coho, and Chum Salmon, and Steelhead Trout in the Pacific Northwest. Reviews in Fisheries Science. 13:22-49.

Rochman, C. 2019. Understanding plastic pollution in the great lakes. Environmental Science and Engineering. [accessed 2019 Oct 03]; https://esemag.com/water/understanding-plastic-pollution-in-the-great-lakes/.

Sigler, M. 2014. The effects of plastic pollution on aquatic wildlife: current situations and future solutions. Water, Air, & Soil Pollution. 225:2184.

Studio, K. A. 2018. Are we running out of water? TED. [accessed 2019 Dec 04]; https://www.youtube.com/watch?v=OCzYdNSFJF-k

Walton, M. 2019, January 21. Desalinated water affects the energy equation in the Middle East. https://www.iea.org/newsroom/news/2019/january/desalinated-water-affects-the-energy-equation-in-the-middle-east.html.

Water Allocation: An Ongoing Challenge [Internet]. 2015. Salt Lake City (UT): Genetic Science Learning Center. [accessed 2019 Nov]: https://learn.genetics.utah.edu/content/earth/waterallocation/

Water Reuse and Recycling: Community and Environmental Benefits.2018. United States Environmental Protection Agency. [accessed 2019 Nov]: https://www3.epa.gov/region9/water/recycling/pdf/brochure.pdf

Water Rights in Montana. 2014. Montana Department of Natural Resources and Conservation, Legislative Environmental Quality Council, Montana University System Water Center. Pg. 1-64.

Yangali-Quintanilla, V., Z. Li, R. Valladares, Q. Li, and G. Amy. 2011. Indirect desalination of Red Sea water with forward osmosis and low-pressure reverse osmosis for water reuse. Desalination 280:160–166.