Agricultural Irrigation Management from the Colorado River

ECL 290/GEO 230: Ecogeomorphology

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Outline:

1. Irrigation from the Colorado River
   a. Groundwater Use
   b. Water Quality Impacts
2. Effects of Climate Change and Drought
3. Agricultural Adaptation and Efficiency
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Abstract:

Most consumptive water use from the Colorado River is used for irrigation, primarily to grow livestock feed. Yet as the population in the region continues to increase and climate change threatens water availability, it is predicted that less water will be available for agricultural use in the future. Irrigation management, including for groundwater, needs to change to improve efficiency and reduce water use. This could include changes to the types of crops grown, when and how much they are irrigated, and upgrades to irrigation technology. Policy is also an important factor to make sure irrigation management is improved effectively, and does not lead to unintended consequences. Additionally, water quality issues such as salinity need to be included in any solution to ensure that water is useable throughout the whole basin.

Irrigation from the Colorado River:

The Colorado River is the most overallocated river system in the world, with the majority of water being used for irrigation. Major irrigation infrastructure was built in 1902 when the Reclamation Act was enacted, which made the spread of agriculture possible in the arid West. Due to improvements in technology, including electrification, chemical fertilizers, and irrigation, agriculture has continued to grow in the Colorado River Basin. As of 2012, 5.5 million acres of land were irrigated with water from the Colorado River (USBR, 2012). This accounts for approximately 62 km^3 of water, or 78 percent of the water used (Cooley *et al.*, 2016). Increasingly, the amount of water used from the Colorado is surpassing the supply. That means irrigation needs to be seriously reconsidered to make sure water can continue to be available in the future, particularly with an uncertain climate future.

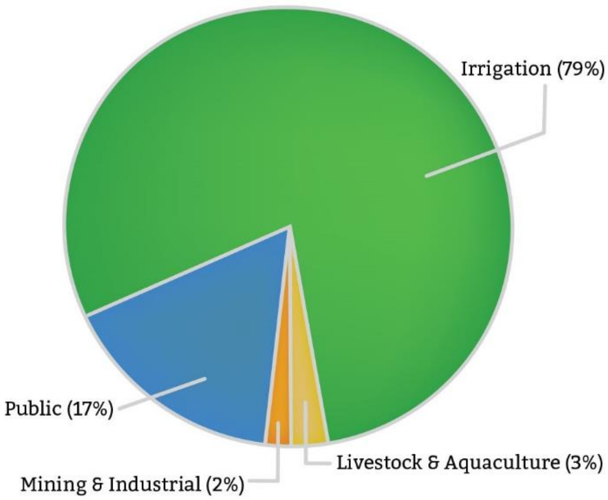

Figure 1. Water use across the seven basin states in 2010 (Maupin *et al.*, 2017)

The food generated from this land accounts for 15% of the nation's crops, 13% of the livestock, and billions of dollars in revenue generated (USBR, 2012). The main crops in the Colorado River Basin are forage crops and alfalfa, as well as wheat, cotton, and other vegetables (Figure 3). Aside from California, which grows more tree crops like fruit and nuts, the vast majority of irrigation (>80%) is for livestock feed and pasture (USDA-NASS, 2014).

	Field and forage		Vegetables, melons, and potatoes		Fruit and nuts		Other crops	
	ha	%	ha	%	ha	%	ha	%
Arizona	288 713	83%	41 671	12%	10 036	2.9%	8 653	2.5%
California	1 379 813	47%	411 985	14%	1 056 248	36%	100 994	3.4%
Colorado	755 781	92%	37 074	4.5%	925	0.1%	23 922	2.9%
Nevada	191 345	96%	3 493	1.8%	487	0.2%	3 270	1.6%
New Mexico	217 282	88%	9 513	3.8%	18 445	7.4%	2 786	1.1%
Utah	348 273	98%	1 556	0%	2 713	0.8%	2 389	0.7%
Total	3 181 207	65%	505 293	10%	1 088 855	22%	142 014	2.9%

Table 1. Crops by type irrigated from the Colorado River (USDA-NASS, 2014)

Due to the Colorado River Compact in 1922, water rights were allocated equally between the upper and lower basin. The vast majority of water is used by Colorado, California and Arizona (USBR, 2012). However, most consumptive irrigation water use, or water that is unavailable for reuse in the basin from which it was extracted, is used by California and Arizona

(Figure 2). On a per acre basis, the lower basin uses four times as much water (Cohen *et al.*, 2013). That's due to warmer climates, longer growing seasons and more water upstream water storage.

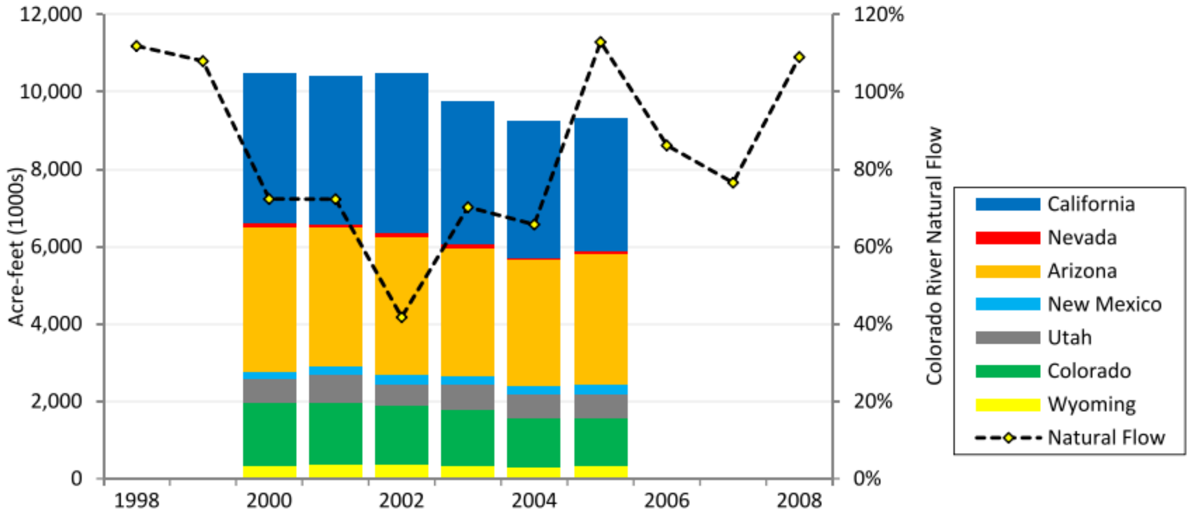

Figure 2. Consumptive water uses for irrigation by the seven basin states (Cohen *et al.*, 2013).

The most common irrigation methods used are not designed for efficiency, but simplicity. About half of the fields in the Basin are irrigated by furrow and another quarter by surface flooding (Kallenberger *et al.*, 2013). These are the easiest and cheapest methods to use based on cost of instillation, but they are also some of the least efficient methods in terms of water use due to high evaporation rates and leaching (Salas *et al.*, 2006). More efficient systems such as micro-irrigation and center pivot systems have been adopted over the past few decades, but only make up less than a quarter of irrigation in the Colorado River Basin as of 2012 (Kallenberger *et al.*, 2013).

Groundwater Use:

Groundwater in an important factor in the Colorado River Basin watershed, especially for irrigation. In the upper basin, groundwater contributes up to half of stream flows, whereas in the lower basin, approximately half of its irrigation water comes from groundwater. (Miller *et al.*, 2016; Maupin *et al.*, 2018). However, groundwater is not allocated in the same ways as surface water. Unlike the highly-controlled Colorado River, groundwater is controlled at a state and local level. In some places, this is leading to overdraft of groundwater, particularly in the lower basin (Castle *et al.*, 2014). Groundwater overdraft can have other harmful effects in the region such as reduced vegetation, land subsidence and seawater intrusion (Zektser *et al.*, 2005). These trends are expected to continue into the future, as water scarcity becomes more of an issue.

Water Quality Impacts:

Agricultural irrigation also has consequences for the quality of water throughout the whole basin. This is particularly true of salinity, where irrigation leaches salts naturally occurring in the soil back into the surface water, increasing salinity downstream. This has harmful effects on crop growth, which disproportionately effect Californian and Mexican farmers (Moore *et al.*, 1974). Salinity and overall water quality should also be taken into account for future irrigation management of the Colorado River.

Low-quality, reclaimed wastewater is also used for irrigation in the lower basin. However, it is generally only used for non-crop irrigation, including for golf courses, parks, and cemeteries (Maupin *et al.*, 2018). In Mexico, untreated wastewater is often used for crop irrigation as well, however this poses serious health risks to farm workers. Improvements to wastewater treatments could provide an additional source of irrigation water.

Effect of Climate Change and Drought:

With or without climate change, water withdrawals are expected to increase in the Colorado River Basin, particularly in the lower basin (Figure 3). This is due to a predicted increase in population and need for more municipal water, which means less water available for irrigation in the future (Dettinger *et al.*, 2015). As the most consumptive use of water in the region, the effects of climate change and drought need to be incorporated into future adaptation and management strategies. Yet, as temperatures rise with climate change, so will the evapotranspiration rates of crops, which means more water will be needed throughout the growing season.

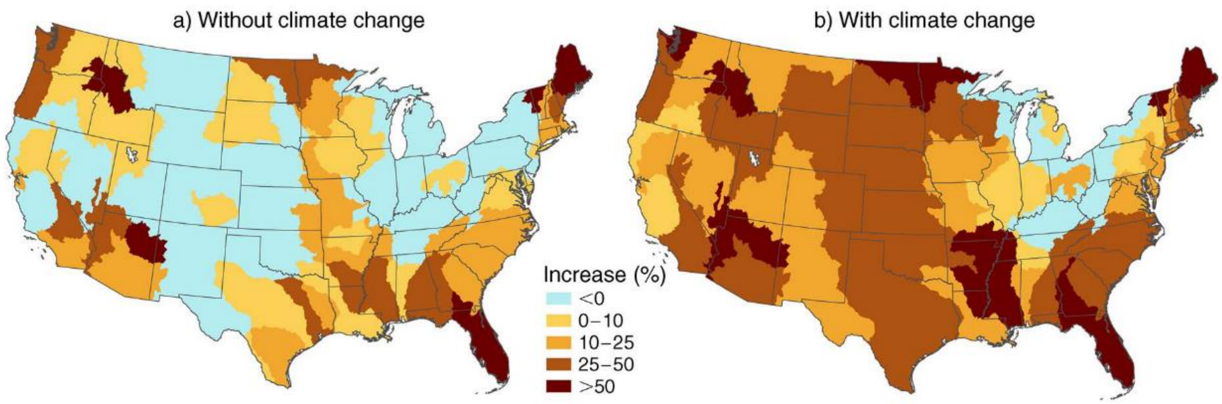

Figure 4. Projected 2005-2060 changes in water withdrawals a) only incorporation projected economic and population growth and b) also including climate change projections under a middle-of-the-road greenhouse gas emissions scenario (Brown *et al.*, 2013).

Elevated CO_2 is directly linked with climate change, and there have been several studies done on its effects on water use efficiency. It has been proposed that crop yields will be stimulated as CO_2 increases from anthropogenic sources since it is a source of carbon that crops use during growth. This has been proven true in some cases, however the other impacts of climate change from elevated CO_2 may negate that benefit. This includes reduced grain-fill, reduced nutrient-use efficiency, and perhaps most importantly, increased crop water consumption (Fuhrer, 2003). Arid regions like the Southwestern United States are predicted to be more affected, leading to a potential overall increase in crop irrigation requirements. However, the water use efficiency has been shown to increase in some crops, including both alfalfa and sorghum, under climate change conditions (Fuhrer, 2003). This can be incorporated into farm management when farmers decide what crops to grow.

Higher frequency of drought is also a likely effect of climate change. Castle *et al.* (2014) points out that groundwater is used at a higher rate than surface water during times of drought. This threatens water security as groundwater discharges contribute to surface water, particularly in the upper basin. During the drought period from 2011 to 2014, more groundwater was also used to reach irrigation demands. It was drawn at a far higher rate than it was replenished, in both the upper and lower basins (Figure 3). This has implications for groundwater availability in the future. If overused, it will likely not be a reliable substitute when less surface water is available year to year. However, if properly managed, the opposite could be true and water could be accumulated in groundwater aquifers to be used during times of drought. Cooley *et al.* (2016) states that aquifers "could help the Southwest region respond to climate change, particularly to reductions in snowpack due to warmer temperatures. With proper management, groundwater aquifers could help capture some of this water, reducing the risk of floods in the winter and drought in the summer." Groundwater and surface water should be managed conjunctively to maintain sustainable usage.

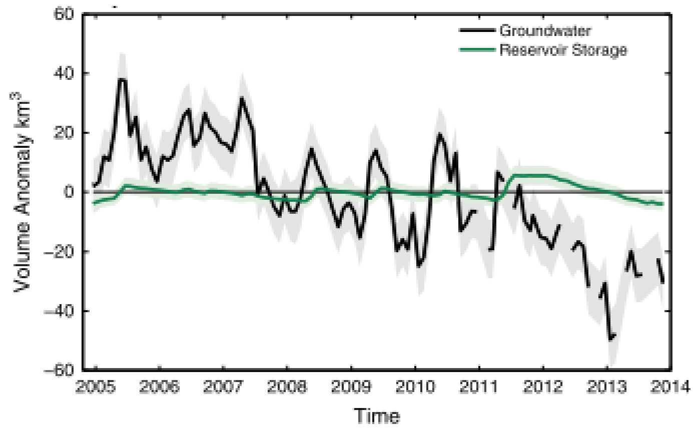

Figure 3. Monthly anomalies of groundwater storage and surface reservoir storage for the Colorado River Basin (Castle *et al.*, 2014).

Agricultural Adaptation and Efficiency:

A great deal of research has gone into increasing efficiency in agriculture. From selective plant breeding to better knowledge on when and how to fertilize, and irrigation management is no exception. Improving water use efficiency can be achieved on a management level by improving irrigation technology and practices. Most irrigation in the Colorado River Basin today is furrow and flood irrigation. These are the cheapest and easiest irrigation methods to install and utilize, but are less efficient due to high evapotranspiration and return flows

Type of Irrigation System	Efficiency (%)
Surface Irrigation	
Basin	85
Border	77.5
Furrow	67.5
Wild Flooding	60
Gravity	75
Sprinkler	
Hand Move or Portable	70
Center Pivot and Linear Move	82.5
Solid Set or Permanent	75
Side Roll Sprinkler	70
Micro Sprinkler	87.5
Trickle Irrigation	
Surface Drip	87.5
Buried Drip	90
Subirrigation	90
LEPA (Low Energy Precision Application)	90
Unknown	75.5

Sources: CIT 1988; Bureau of Reclamation (no date); Kruse et al. 1990; Keller et al. 1981; Roe 1950

Table 2. Irrigation efficiency by type of system (Salas *et al.*, 2006)

(Salas *et al.*, 2006). Moving sprinklers and pivot irrigation has also grown in popularity (Maupin *et al.*, 2018). Though they are slightly more expensive, they also use less water as they are 10 to 15 percent more efficient. On the extreme end of cost and efficiency are micro-irrigation and sub-surface irrigation, which boast up to 90% water use efficiency (Table 2). These are slowly being implemented, particularly in California. However, one drawback of micro-irrigation is a build-up of soil salinity. As previously stated, irrigation flushes additional water and salts dissolved from soil, back into surface water. With highly efficient irrigation systems, water and dissolved salts are not leached through the soil profile and salinity can build up in the soil around the root zone and cause damage to crops (Burt *et al.*, 2003). Therefore, micro-irrigation should be focused in less salty soils or with more salt-tolerant crops.

Many see precision agriculture as the next big step in increasing water use efficiency. This would utilize granular, real-time monitoring and automation to address each individual plant's watering needs to make sure the exact amount of water needed is used. This includes the use or remote sensing using geographic information systems, as well as remote soil moisture monitors. It could also include an automated feedback-controlled irrigation system where it triggers watering when a certain threshold is passed. Precision irrigation can save around 10 to 15 percent more water than conventional irrigation (Sadler *et al.*, 2005). However, so far, the economic projections are not favorable for this technology, which is a significant barrier to implementation.

Beyond irrigation techniques, farmers can change what or how they grow to reduce water use. Changing what to grow is called crop shifting, where water-conscious farmers can choose to grow less water-intensive crops or crops that have shorter or cooler growing seasons. In the southwest, this may mean shifting from cotton to wheat or alfalfa to sorghum (Fuhrer, 2003). Changing how to grow crops could include managing soil to increase water holding capacity. This usually means increasing the organic matter content through conservation tillage (leaving residues in the field) or mulching, which adds additional benefits such as nutrient buffering and improved soil structure (Williams *et al.*, 2016). Another management tool could be deficit irrigation. This is where, instead of trying to get the most yield per area, farmers get the most yield per volume of water applied or "crop per drop." This means that crops would be watered less, but might also produce less yield overall, which could be an issue for profits (Varzi and Grigg, 2019). These methods have in fact been successful in the past, with freshwater withdrawals in the region decreasing by 18 percent from 1990 to 2010 (Cooley *et al.*, 2016). Farmers will need to continue adopting these large-scale management changes to reduce irrigation water use in the future.

Future Scenarios:

The Colorado River Basin currently supports 50 million people. That population is predicted to increase by 23 million between 2020 and 2030 (Miller *et al.*, 2016). That means more water will be needed for municipal use, which likely means less will be available for irrigation. Furthermore, groundwater cannot be taken for granted. Overallocation of groundwater, particularly during times of prolonged drought threatens water security. As research continues, as does development in irrigation technology and management strategies, water use efficiency can continue to increase. This includes the methods mentioned above as well as changes to policy to encourage changes in irrigation management.

However, as several studies have shown, increased efficiency may not necessarily lead to less water usage. Ward and Pulido-Velazquez (2008) found that increased economic incentives for farmers to adopt water conservation practices, in fact increased water usage in the Upper Rio Grande Basin. This can be attributed to water being made cheaper for farmers to grow even more crops. Furthermore, when more efficient irrigation practices are used, there are less return flows and aquifer recharge since all water that is drawn is used. Research needs to be taken into account when making policy to make sure that unintended negative consequences do not exacerbate the problem.

Another option is to simply decrease the quantity of crops grown in this region. As discussed previously, the majority of irrigation in the Colorado River Basin is used to grow forage crops and pasture land, which are all used to feed livestock. One avenue that must be considered in the future is less animal agriculture. Studies have shown that livestock has a water footprint significantly higher than plant-based foods. Also, grazing systems have a higher water footprint than mixed or industrial systems for raising livestock (Gerbens-Leenes *et al.*, 2013). However, the broader impacts of shifting away from animal agriculture in this region do not appear to be well-studied. What is grown is largely dependent on economics and higher water costs in the future may reduce the viability of growing crops or raising livestock when water is more limited.

Conclusion:

The problem of irrigation from the Colorado River under growing water stress is difficult as growing crops and livestock are vital to the region, both for sustenance and economically. Groundwater and water quality issues add even more complexity. The effects are already being felt by farmers across the region, who recognize the need for adaptation and change. Luckily, there are several new policies, technologies, and behaviors that can be implemented to reduce water use from irrigation. While it remains unclear which strategies will win out in the end, there is momentum towards finding a solution. Basic research needs to continue in order to develop the best future outcomes for irrigation management, for both increasing efficiency and predicting outcomes.

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