Of Silt and Ancient Voices: Water and the Zuni Land & People

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Red Cliffs of Entrada Sandstone, New Mexico
Photo source: USDA-NRCS (2005)

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The Justice Department team huddled in the hallway of the U.S. Court of Claims. Judith sat in the judge's chambers, nervously eyeing the curious mix of Harvard Law teak & leather and government grey steel. Today was decision day on the settlement, and she had brought the cell phone that the firm had just given its associates, pleased that this new one fit in her purse. The rolling attaché at her side packed with depositions from anthropologists, engineers, economists and soil scientists, her mind drifted to the black rock and red beds, the sweet smell of juniper and pińon, and the tears of the Pueblo's elders.

Judith reflected back on the beginning of the case while she nervously thumbed through a folder of court exhibits. She first travelled to Zuni Pueblo a year ago, armed with only a rudimentary understanding of the issues at hand. She arrived in Albuquerque, New Mexico on a blazing hot, dry day in mid-August. The heat only intensified as she drove west from the airport towards Zuni Indian Reservation into the scorching sun, crossing through a desert spotted with scraggly sagebrush and juniper. She drove onto the Zuni Reservation, arriving just minutes before her meeting with the Zuni tribal council. All she knew at that point was that Zuni Pueblo had brought suit against the U.S. government for desecration of trust land.

When she exited the town hall in Zuni Pueblo three hours later, the sun had fallen and the temperature had already dropped dramatically. She grabbed a sweater, wrapped it around her shoulders, and set out in her rental car. She calculated that she could visit at least a few important sites before nightfall. As she drove, her mind raced, reviewing all that she had learned from the Zuni elders and citizens that evening. She headed toward the Black Rock Dam and Reservoir, the primary source of contention. The Zuni argued that the Black Rock Irrigation Project, which was forced upon them by the U.S. government, led to the social, economic, and environmental degradation of the reservation.

Exhibit. Accelerated rates of soil erosion and arroyo development on Zuni lands, pictured here in 1933, were of concern to the tribe, and attracted the attention of some federal officials, such as noted soil conservationist Hugh Hammond Bennett (Helms 2008).

As she approached the dam, Judith pulled over onto the road's shoulder. She grabbed her camera bag and set out on foot. As she walked, she noticed, for the first time since her arrival, the deep gullies cutting into what was once prime Zuni grazing land. Was it possible that the gullies were just a natural phenomenon, or were they the result of land-management decisions by the U.S. government, as the Zuni elders argued? She stopped to snap a few photos that she might use as exhibits in the case. She continued on toward the dam, climbing the embankment to the shoreline of the reservoir. As she looked in the direction of the sacred spring of the Zuni people, now covered in water and silt, she wondered: What is the price of progress? It seemed unforgivable that the dam's engineers should have so callously ignored its effect on the Zuni culture. She then turned and snapped a *picture of the gauge at the dam face, hoping to later tie that to the 1910-1980 historical record showing declining reservoir capacity and declining volume of irrigation water supplied to Zuni farmers from Black Rock Reservoir. She had to wonder whether the U.S. government engineers understood the impacts of their land and water policy decisions on erosion within the watershed. Not to mention the impact of those policies on the Zuni way of life, which could no longer revolve around agriculture that was closely tied to sustainable land management designed to conserve scarce water.*

A door banged shut in a nearby hallway, abruptly bringing Judith back into the present. She was on edge, waiting for a decision. Had she made her case? And was there a way back for the Zuni people?

Part 1. Survival in a Harsh Environment: Imagining Zuni Strategies for Resource Management

This first section of the case study introduces you to the Zuni landscape and people as they existed prior to western U.S. expansion into the region. Read Handout 1, then discuss the following questions with your group.

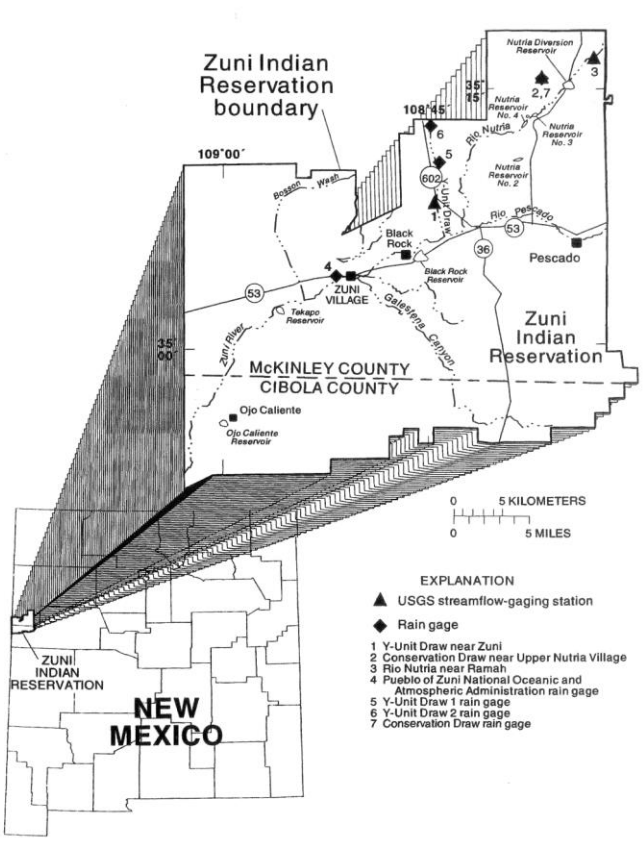
1. Identify the elements of survival in this harsh environment: food, clothing, shelter.

2. Describe at least three methods you imagine the Zuni may have used for watering their fields.

Handout 1. Background on the Zuni Land and People

The Zuni are a federally recognized American Indian tribe with approximately 12,679 members according to the 2010 Census (U.S. Census Bureau 2013). At the time of first Spanish contact in 1539, the Zuni occupied six or seven large pueblos in what is now western New Mexico (James 1997). Archaeological evidence indicates the Zuni had been living in this area for over 3,000 years, although they did not move from farming villages into very large pueblos until the mid-13th century (Ferguson 1996). They experienced relatively little direct Spanish contact for the remainder of the 16th century, yet it is likely that they lost much of their population due to the spread of introduced European diseases. During the 17th and 18th centuries, the Zuni revolted against Spanish incursions into their territory, and at times the Hopi (pueblo Indians from northeastern Arizona) moved in with the Zuni (James 1997). The U.S. government took control of Zuni territory in 1846, and in 1877 the first acreage was set aside to form the Zuni Reservation.

The Zuni live in an area known as "Zuni Pueblo," located in the southeastern portion of the Colorado Plateau, a scenic, arid, 140,000 square mile (360,000 square kilometer) region with an average elevation of 5,200 feet (1,585 meters). The region is roughly centered on the "Four Corners" area, where Arizona, New Mexico, Colorado, and Utah meet. The vegetation in this area is classified as Colorado Plateau shrublands. To the untrained eye, the landscape looks rather bleak, with low trees and shrubs scattered among sparse grass and herbs. However, the Colorado Plateau ranks within the top five ecoregions in continental North America in terms of species richness in plants, mammals, and a number of insects (Nabhan et al. 2002).



Map of the Zuni Indian Reservation
Image source: Gellis (1998)

The Zuni live in an area with very little surface water. New Mexico ranks 4th lowest among the 50 states in terms of annual average precipitation. Unpredictable and scattered rainfall amounts to about 10 inches (25 cm) per year (the average from 1901-2000 in the contiguous U.S. is 29.14 inches per year, NCDC 2013). The rain and snow that fall within the Zuni River watershed run off, feeding the Zuni River, or infiltrate the soil and recharge the groundwater system. Soils are derived from a variety of "parent materials," the term soil scientists use to describe the igneous and sedimentary rocks of the region that give rise to the soils by weathering. The soils that result from that process vary in porosity and their ability to retain water.

The Zuni language is an isolate, meaning that it is unlike any other North American Indian language. As of 2000, nearly 73% of the Zuni people still use their language in the home, but the majority are also conversant in English (Ethnologue 2013). Like other southwestern puebloan societies, the Zuni were matrilineal, tracing descent through the female lineage. They also were matrilocal, meaning that a newly married couple lived with the wife's family (James 1997).

At European contact, the Zuni traditional way of life relied on farming to raise crops such as maize, beans, squash, and cotton; collecting wild plant foods such as pinyon nuts; and hunting wild game such as deer. The Zuni kept caged wild eagles and raised turkeys to supply feathers for religious purposes (Ford 1985:81,122).They eventually adopted livestock from the Spanish, particularly sheep and, to a lesser extent, goats (Ford 1985:116). Sheep were raised mostly by men for wool (woven into articles by women) and meat. The Zuni likewise adopted the field and orchard crops of peaches, watermelons, and muskmelons from the Spanish, along with the garden plants of coriander, onions, and chili peppers (Ford 1985).

Zuni religious beliefs affected their management of resources, including cultivation of crops and hunting wild game (Ford 1985). For example, the Zuni believed that "ritual is necessary to produce water" (Ford 1985:59). The Zuni used every portion of their extensive territory to collect plants for food, medicine, ceremonies, fuel, and construction (Ford 1999:82). Traditionally, Zuni men managed the agricultural fields, often located far from the Pueblo, and women managed smaller gardens located near the villages (Ford 1985,1999:79). Zuni men traditionally employed three methods of watering fields, sometimes using more than one method in the same field (Ford 1999). The Zuni practiced many techniques to reduce or lessen the risk of crop failure. For example, the practice of planting smaller fields in various locations lessened the risk that any one large field in one particular location would not receive enough water that year.

Part 2. Zuni Resource Management Challenges through the Lens of an Expert Witness

Judith sighed as she thought about all the late nights she had spent in her office, devouring fast food and endless pots of coffee. All of those hours spent scribbling on legal pads and white boards in an attempt to reconstruct in her mind the vibrancy of the Zuni Pueblo as it was before westward U.S. expansion! She couldn't help but feel a little unsettled. Her vision of the traditional Zuni sat in stark opposition to their current state. What had led to such a dramatic change? She pulled out that initial briefing document, flipping pages until her eyes landed on the timeline that she already knew backward and forward. She stared at the page, unseeing, letting her mind drift over the chain of events...

Part 2(a). A Time of Change
Handout 2 picks up where Handout 1 leaves off, providing background on the construction of the Black Rock Irrigation Project and its effects on the Zuni. Take a few minutes to read this material.

Part 2(b). Becoming the Expert
The construction of the Black Rock Irrigation Project generated far-reaching cultural, economic, and environmental impacts for the Zuni people and landscape. For the remainder of the case study exercise, you will take on the role of a witness with expertise in a particular field of study. You will work with other experts in the same field of study to draft a report either (A) anthropology – outlining Zuni land management techniques; (B) soil science – explaining the implications of the irrigation project on Zuni farming; or (C) economics – explaining the impacts of the irrigation project and the rationale behind U.S. government policies pertaining to water management. Take a few minutes to read the handout provided for your expert group (Handout 3A, 3B, or 3C), familiarizing yourself with the evidence that you will use in your report. Then discuss the questions at the end of your handout as a group, and use that discussion to draft your report.

Handout 2. Briefing Document: A Time of Change

Though the Zuni had a long history on the Colorado Plateau, the movement of U.S. settlers westward ultimately changed the landscape of Zuni Pueblo and the livelihoods of the Zuni people. The late 19th century saw the establishment of a U.S. military fort and a railroad across Zuni territory. Following those events, western settlers began mining, harvesting timber, and grazing livestock across the region (Ford 1999). Though all of these activities all contributed to change in the Zuni environment and way of life, perhaps the most dramatic changes occurred with the construction of the Zuni Irrigation Project in the early 20th century.

The momentum behind the Zuni Irrigation Project can be attributed in part to the Homestead Act, and in part to a change in U.S. attitudes about agricultural production in the arid West. The Homestead Act of 1862 opened the Indian Territory in the vicinity of present-day Oklahoma for the establishment of 160-acre homesteads by non-Indians at little or no cost. In exchange for the deed to the land, homesteaders agreed to live on the land, invest in improvements, and farm the land for at least five years. The vast U.S. West provided ample land for homesteading, but settlers familiar with agriculture in the humid East soon realized that a lack of consistent water for irrigation rendered agricultural production extraordinarily difficult. As homesteads failed due to variable and unpredictable rainfall and periodic drought, the question became how to support agricultural expansion into areas like the Zuni territory.

The answer to that question was heavily influenced by the voice of John Wesley Powell, an anthropologist and early explorer of the West. In the course of Powell's adventures, which included the first rafting trip through the Grand Canyon, he came to believe that the majority of lands in the West were unsuitable for agricultural production without federal intervention to provide water for irrigation. In his *Report on the Lands of the Arid Region of the United States*, Powell argued that addressing this problem was of pressing importance given the westward migration of thousands of settlers annually and advocated for federal support of irrigation development, noting that:

> The diversion of a large stream from its channel into a system of canals demands a large outlay of labor and material. To repay this all the waters so taken out must be used, and large tracts of land thus become dependent upon a single canal. It is manifest that a farmer depending upon his own labor cannot undertake this task. (Powell 1879:11)

In 1902, the U.S. government followed Powell's advice, enacting the Reclamation Act which called for federal support of the construction and maintenance of large-scale irrigation infrastructure, including dams, reservoirs, and canals, across the West. Shortly thereafter, on July 22, 1903, Congress approved the construction of the Zuni Irrigation Project, one of the largest public works projects in the U.S. The Zuni Irrigation Project consisted of the Black Rock Dam and a network of downstream irrigation canals (Ford 1999:83). The Black Rock Dam was constructed from 1904 to 1908 in a basalt canyon northeast of the Zuni Village (Dodge 2008:87-91). Land downstream from the Black Rock Dam and Reservoir was sectioned into allotments fed by a series of irrigation canals.

The engineering was not without problems, and a major dam failure occurred in September of 1909, following very high rainfall in the region. In the aftermath of the huge volume of water that rushed down the valley below the dam, the landscape was described as looking like a war zone (Dodge 2008:93). The dam failed again in 1936 (Dodge 2008:158).

The Zuni Irrigation Project almost immediately began to suffer from a number of problems. Erosion caused by upstream timber harvesting and livestock grazing caused silt to build up behind the dam, leading to a public safety crisis within two decades of the dam's completion (Ford 1999:83). As silt filled the reservoir, less storage capacity remained for water and the dam was unable to buffer seasonal variability in inflows, which increased the risk of catastrophic flooding. The same problem applied to smaller earthen dams that had originally been constructed by the Zuni, but later increased in size as part of the Zuni Irrigation Project. The silt build-up also reduced the amount of water flowing into irrigation canals to the extent that so little flow remained for irrigation that water rarely made it the full length of the canal system (Ford 1985).

The construction of the Irrigation Project also directly affected the Zuni by destroying a sacred site. During construction of the Black Rock Dam, workers desecrated a sacred spring that once housed *Malokyatsiki*, the Salt Mother, according to Zuni folklore (Ford 1999:84). The spring was subsequently covered with water and eventually buried by the silt that filled Black Rock Reservoir.

The Black Rock Dam in the Zuni Irrigation Project
Photo source: Gannett Fleming (2002); reproduced with permission of Gannett Fleming, Inc.

Even if the dam had provided sufficient water for irrigation, another dilemma soon became apparent. The land served by the Zuni Irrigation Project primarily consisted of tight clay soils, *hepecha* in the Zuni language, which had never been used by the Zuni to produce their most essential crops – corn, beans, or squash (Ford 1999:77). The Zuni sometimes used *hepecha* to produce wheat, but yields were typically low and cultivation required large amounts of labor to combat the weeds that flourished there. Despite the limited utility of this land for crop production, the U.S. government forced the movement of the Zuni people and agriculture onto these lands in the Irrigation Project (Ford 1985). The U.S. also implemented a system of private property rights under the General Allotment Act of 1887, in which scattered individual and communal Indian lands were divided into private contiguous parcels and allotted to individuals. With that Act, traditional Zuni production practices—which relied on owning many small, scattered farm plots; some communal property management; the concentration of labor in villages; and free-range livestock grazing—came to an end (Ford 1985).

During the mid-1800s, prior to extensive settlement by non-Indians, the Zuni territory included more than 15 million acres. The Zuni cultivated about 10,000-12,000 acres for crops, raising a surplus of corn that was sold to U.S. army posts in the region. The Zuni sheep grazing area extended over about two million acres. The U.S. government encouraged non-Indian settlement of the region in the latter half of the 19th century. By 1876, the area under Zuni control had been reduced by about 60%. Logging and grazing, as well as farming by non-indigenous settlers, displaced the Zuni and restricted their access to their aboriginal territory. The logging and overgrazing caused extensive erosion. In a water-limited region, where access to a diversity of lands and large territories per capita was needed for survival, the combined effects of environmental degradation and land restriction were dramatically altering Zuni life (Hart 1995:92-93).

The General Allotment Act of 1887 divided tribal land into tracts and granted each Zuni individual over the age of 18 years 80 acres of land and heads of households 160 acres: any surplus was opened to non-Indians. With the coming of Black Rock Dam and the Zuni Irrigation Project, the irrigated allotment was reduced to 5-10 acres. The confluence of reduced acreage and a quickly failing irrigation system, with inadequate water supply, was devastating for the Zuni farmers. The acreage cultivated fell to 5200 acres in 1934, 2200 acres in 1968, and a mere 1400 acres in the early 1990s (Dodge 2008:81,85,96; Hart 1995:96). Further inroads into Zuni knowledge of land management techniques and important rituals were made when Zuni children began to attend boarding school in 1903, where they were punished for speaking their language or attending ceremonies (Dodge 2008:106, 113-121).

Handout 3A. Expert Witness Materials: Anthropology

The worldview of the Zuni influences their beliefs and actions. The Zuni consider themselves to hold a kinship relation with nature, and each has mutual obligations to the other. The surface of *awitelin citta*, or Earth Mother, must be respected: massive surface disturbance, such as plowing, is offensive and causes the soil to dry out. Only carefully dug holes made with a digging stick for planting seeds are acceptable (11).[1] The Zuni recognize several sources for their food plants and animals. The oldest foods (both domesticated and wild), which have myths to relate their origin, came from what the Zuni refer to as the "raw [original] people." The plants brought by the Spanish and Americans generally have a name derived from these foreign languages (18-19). Maize, which is the basis of Zuni cultural life, is used in all ceremonial occasions (20). Like the Hopi, another puebloan people in the Southwest, the Zuni developed a special maize that has the unique ability to be planted almost a foot deep in order to take advantage of the moisture available below the land surface (our modern maize must be planted just below the surface to survive). The Zuni use certain colors of maize for their rituals and maintain fields in various locations to ensure that the colors remain pure. Scattering fields in various habitats additionally reduces the risk of total crop failure, especially in this arid environment where rainfall can be very localized (Cleveland et al. 1995:5).

The essence of Zuni ceremonialism is the bringing of water in the form of rain or snow (49). General weather control is the responsibility of the many ceremonial groups (15). Only proper behavior, ceremonies, and rituals bring the rain clouds. Clouds are the breath of the gods and smoke (13-14). Water, which is a blessing from the raw people, must not be wasted (11, 14). *Uwanami*, or rain-makers, reside in springs (11). Lakes and springs can be used for drinking and agriculture so long as the water is shared harmoniously and without overconsumption. Runoff should be directed to the plants for their life and not permitted to go unused or to violate Mother Earth by washing away her soil (14-15). The Zuni Frog clan maintained a spring sacred to all Zuni, which is now buried underneath silt in the Black Rock reservoir. It was 15 by 20 feet in size with terraced ledges beneath its surface. Special pottery bowls made to hold feather offerings were placed on the ledges (131-134).

Traditionally, farming was based upon beliefs and hard-won experience (92). Farming, gardening, and herding were for domestic consumption and ritual sharing, and only after those needs were met was any surplus for trade or sale (91). Fields were carefully placed in locations with seasonally moist alluvial soil such as in canyon bottoms, along rivers and streams, and at the mouths of arroyos (Cleveland et al. 1995:5). Among the Zuni, men tended the agricultural fields, and women tended smaller gardens (59-60). Maize and beans were grown in fields, as was wheat after it was introduced by the Spanish. The principal crops grown in gardens included Spanish-introduced coriander, onions, chili peppers, watermelon, cantaloupe, and garlic. Additionally, they grew vegetables introduced by U.S. settlers. Gardening produced more predictable sources of food than did farming. The Zuni developed their own varieties of maize, beans, and squash adapted to growing successfully in such an arid environment with a short growing season (Cleveland et al. 1995:6-7).

The Zuni attribute useful weeds in their fields to three sources. The ultimate source is the rain gods, who send seeds inside hailstones and with heavy rain. The Zuni themselves scatter wild seed that was distributed at Night Dances, but they also recognize natural means of seed dispersal. Only useless weeds are removed from the fields, whereas useful plants are permitted to grow (113). Wild plant seeds are mentioned in prayers and are carried in bags during ceremonies (70). The Zuni did not plant pinyon or other useful native wild trees, believing that one's life was shortened for each year the tree lived (114). However, they did plant peach orchards following the introduction of the fruit trees by the Spanish.

[1] Unless otherwise indicated, references are from Ford (1985), with specific page numbers in parentheses.

The Zuni traditionally employed a number of agricultural methods to conserve as much water as possible. The particular soils and topography dictated which method was used. In run-off farming, the farmer constructed a "V" of branches covered by soil perhaps as far as 50 meters upslope from a field to divert a flow of water and direct its path. Low earthen banks then intercepted the diverted water, until it was reduced to small volumes (34). In flood-water farming, the farmer used a series of small brush-and-earth dams in a herringbone pattern to deflect flood water out of the stream bed to evenly spread it over an entire field. To use this method the stream channel must be kept close to the level of the field – it will not work if the stream is in a gully or down-cut arroyo (37). Sometimes when the water was in an arroyo or starting to create a gully, the farmer built a post-and-brush dam that not only raised the water onto the fields, but acted to retard the flow of water and hold any soil, causing the arroyo to grow shallower over time (39, 69). The Zuni built a few water canals from springs and reservoirs to irrigate fields (41).

The internet has truly made us an interconnected planet. And yet even in an earlier era, when most lives were lived in complete isolation from distant peoples, it is interesting to note that creative solutions, similar to what the Zuni used to slow down or divert water to their fields for irrigation, were used for water management in other parts of the world. For example, these pictures from late 18th century Germany show similar types of permeable dam construction using pliable branches from trees such as willow to form bundles called "fascines." These bundles were used in the flat, marshy region of Prussia to create dikes for flood control. Fascines are still widely used today in streambank stabilization efforts.

The Construction of Fascines in Prussia in the 18th Century

Image source: All three images are clips from a single image in H.C. Riedel, jun. Riedel, H. C., jun., "Über unvorhergesehene Unfälle bey Coupirung der Deich Durchbrüche," *Sammlung nützlicher Aufsätze und Nachrichten die Baukunst betreffend* Bd. 3.1 (1799): 24-53, Table II. Images from Olesko (2010); reproduced with the permission of Kathryn M. Olesko, Department of History, Georgetown University.

The women maintained "waffle gardens" in the Pueblo. These were walled with adobe or fenced with upright wooden posts that were sometime covered in adobe, in order to keep out children, dogs, and livestock. Inside the enclosure, 12-18 inch squares of ground were walled with four to six inches of sand. The squares were arranged in pairs with pathways in between, for easy access. Women watered each square by pot irrigation, which involved retrieving pots of water from walk-in wells in the Pueblo or from the Zuni River (60). They used gourd dippers to transfer the water from the pots to each square, applying four dippers of water every three days (61). Sometimes women built pen gardens directly next to an irrigation ditch. Much larger than waffle gardens, pen gardens were watered with small, feeder canals (62). Pen gardens also were built with low, mounded soil edges, but the areas enclosed were large.

Prior to European arrival, the Zuni herded turkey. They adopted herding of sheep and some goats from the Spanish (25). They plucked the wool rather than shearing it. Generally, men owned sheep, and they were always attended by men or boys, who kept flocks from overgrazing any one area, which they could do because they grazed large areas outside the Pueblo vicinity (117). They knew how to burn to increase grass production (69). Zuni limited the size of their flocks by slaughtering many animals for ceremonial feasting at certain times of the year (117). Sheep were raised for wool and meat; goats were raised for wool, meat, and milk.

Planting a Waffle Garden at Zuni Pueblo, 1911

Image Source: Courtesy of the Palace of the Governors (State of New Mexico History Museum). Photo Archives, Jesse Nusbaum Collection. http://econtent.unm.edu.

The Zuni were successful at living in a harsh environment with low and uncertain rainfall, hail, damaging wind, and grasshopper plagues (93). Early U.S. visitors were impressed by Zuni generosity and life-saving hospitality (140). It was Zuni practice to store at least two years of maize crops at harvest time, although they often were not able to do so. If someone was ill or died during the agricultural cycle, others would step in to help the family. The ritual cycle aided everyone. People gave food to the religious societies, who then redistributed it to the community (93). Farmers did not plant a field until it had stood ready for a year, accumulating silt, and giving the farmer time to observe and correct the flow of floodwater from his dams (98). They built small brush fences perpendicular to the prevailing wind to keep sand from blowing onto young plants (139), and they left the stalks in the field to help capture wind-blown silt (Cleveland et al. 1995:5). "With many centuries of traditional practices of land management behind them and an effective belief system from time immemorial, the Zuni integrated new crops and animals without recognizable destruction to the land" (122).

Discussion Questions:

1. Compare and contrast your worldview with that of the Zuni. What are the implications for how you versus the Zuni would approach land, plant, and animal management?

2. How do Zuni dams differ from the dams we usually see placed on U.S. rivers and streams? Do we use any dams similar to Zuni dams, and if so, where or for what?

3. List the ways in which the Zuni traditionally managed to live successfully in a harsh environment. Note that not all of these are listed in the final paragraph.

Handout 3B. Expert Witness Materials: Soil Science

Soil is a key component of any agricultural system. Soil has been described as a sponge — a solid matrix and a network of pores that can hold water. Plants on land derive their water via their root system from this "sponge." The Zuni people used several terms to describe their soils as follows:

1. Sand (*so:we*). This soil is regarded as outstanding for corn, beans, and squash. In drainage bottoms with high sub-surface water tables, it supports corn fields. Where water is deep, then squash or beans may be given preference to corn. Peach orchards are planted on dunes.
2. Loam (*helyalo:we*). This soil is ideal for corn. It is usually found in tributary valleys, the bottoms of major drainages, and the outwash fans of seasonal streams. This is the favorite soil for raising corn.
3. Clay (*hepecha*). Clay is found in patches in the farming villages, irrigated land, and in greatest abundance in the Zuni Irrigation Project. The cohesiveness of the minerals make the soil "tight," more difficult to cultivate using traditional methods, and hard for germinating seeds to penetrate the surface. It also supports a luxuriant growth of weeds requiring extensive work to remove. Wheat is generally grown on this soil and, more recently, alfalfa. It is the least preferred soil for corn. The Zuni believe that corn is more difficult to grow on this soil because of the labor required and the potential for greater run-off. A variety is *lupopo:we*, which is a crust of clay that forms on irrigated land. It must be broken in order for the plants to obtain water and to exchange gas at the shallow root level. Another variety is *makose:we* or alkaline soil in irrigated areas. This is commonly found in Ojo Caliente.
4. Adobe. This soil is thick clay and is not used for fields. Occasionally patches of this clay soil are mixed with animal manure and thus converted to gardens (*hekkowetsanna*) but ordinarily it is not devoted to agricultural purposes. Single fruit trees may be set here. (Ford 1985:29-30)

Here is a link (http://soils.usda.gov/survey/online_surveys/new_mexico/) to the U.S. Department of Agriculture soil survey report for McKinley County, New Mexico, the location of the Black Rock Dam and a major portion of the Zuni Pueblo (USDA-NRCS 2005). It uses a different soil classification system. This is a massive report (683 pages without the accompanying maps). For our purposes here, please focus your attention on the description of the Aquima Series soils (pp. 160-161).

Particle-size distribution is major factor considered in the soil classification systems currently used by federal agencies, and most soil scientists in the United States and Canada. The term "soil texture" refers to a measure of the percentage of particles of various sizes in the soil, typically classified into:

- sand (the coarsest; feels gritty; diameter range: 0.05 to 2.0 millimeters);
- silt (the intermediate size fraction; has a smooth or floury feel; 0.002 to 0.05 millimeters); and
- clay (the finest; feels sticky; diameter less than 0.002 millimeters) in the soil.

Soil texture influences:

- the ease with which soil can be tilled by hand or machine for planting crops;
- the amount of pore space present and thus the amount of water and air the soil can hold; and
- the rate at which water can enter (infiltrate) and move through soil.

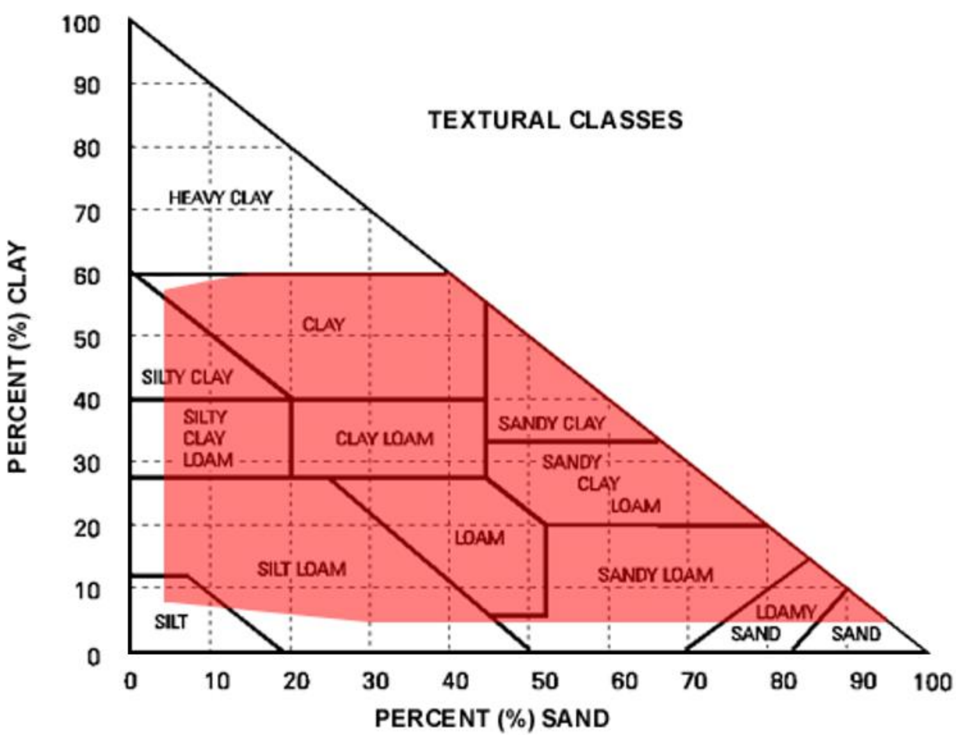
The ability of soil to hold water is critical to plant growth. This is particularly true in the arid lands occupied by the Zuni. With the on-line calculator below, you can explore water-content parameters related to plant growth. Today we will focus on "plant-available water," or the quantity of water that can be held in the soil's pore spaces in a manner that plant roots are neither waterlogged (too wet) or drought-stressed (too dry). Such water is thus available for root uptake and the production of crops.

The Soil Texture Triangle Hydraulic Properties Calculator (http://www.pedosphere.ca/resources/texture/triangle.cfm?358,298) is a fast and informative way to see how changing the percent sand, silt, and clay changes the available water content. The classification system shown in this calculator is used in Canada, but a similar system, used by the USDA, exists in the U.S.

Triangular graphs such as this are commonly used in geology and soil science to represent mixtures of three components, but may at first appear strange to you. As a test case, consider a soil with 70% sand and 10% clay. Go to the bottom of the triangle and put your pointer at the 70% mark on the "PERCENT (%) SAND" axis. From here, move upward to the first horizontal line (10% clay). A soil at this intersection on the graph has 70% sand, 10% clay, and by difference, 20% silt. It is classed as a "sandy loam." Now please take a few minutes to freely explore all parts of the shaded area of the triangle before moving to the questions.

Discussion Questions:

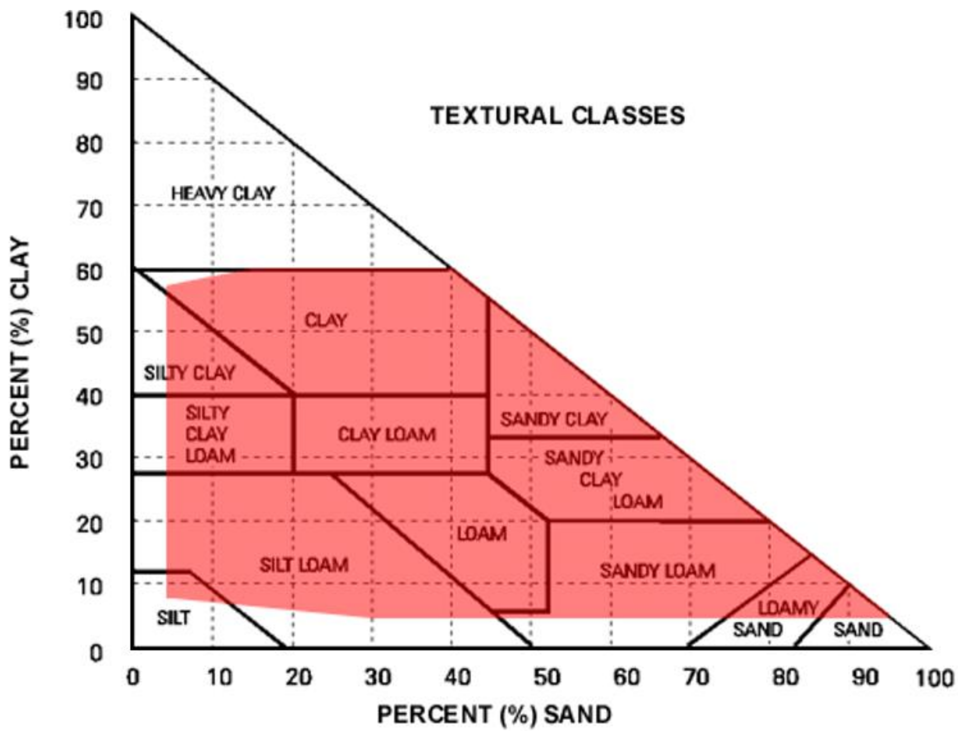
1. Find a point near the center of the shaded portion of each textural class (such as "clay loam"). Annotate the soil triangle and space below by recording the value for available water at each such point. Do you see trends as you move in various directions from one portion of the triangle to another?



2. Soil scientists look not only at the soil at the surface, but also at the layers ("horizons") below. With knowledge of the entire soil "profile," they can learn how the soils formed from underlying earth materials, predict rates of water infiltration and retention, and assess the ability of roots to

penetrate to various depths. Please look at the description of the "Typical Pedon" for the Aquima soil and answer the following:

- Is the texture uniform with depth?
- Please show any variation by marking on the soil triangle below.
- If any textural classes are not contained on the triangle, please note that name and depth of occurrence.
- What textural class does it seem to be similar to?
- How do you think its difference from this similar soil will influence its plant-available water content?
-



3. Under the description of clay (*hepecha*) is the statement: "A variety is *lupopo:we*, which is a crust of clay that forms on irrigated land. It must be broken in order for the plants to obtain water and to exchange gas at the shallow root level." Answer the following:
   - How may the clay layer affect plant growth?
   - Where do you think the clay that forms the crust comes from?
   - Once that crust is broken up, how might the presence of these clay materials be a good thing for crop production on these soils?

4. In the description of clay (*hepecha*) is the statement: "Clay is found in patches in the farming villages, irrigated land, and in greatest abundance in the Zuni Irrigation Project." What are the implications of this distribution for the Zuni farmers?

5. How would the Zuni farmers likely classify the Aquima soil? Be prepared to explain your answer.

Handout 3C. Expert Witness Materials: Economics and Policy

Zuni ownership of land and resources was mixed. Individuals held control over their own farmland, yet they acknowledged overall community regulation. Land traditionally was passed down through the women: today inheritance is through either parent or by marriage (Cleveland et al. 1995:3-5). General weather control was the responsibility of the many ceremonial groups. Lakes and springs could be used for drinking and agriculture so long as the water was shared harmoniously and without overconsumption. Zuni tradition held that runoff should be directed to the plants for their life and not permitted to go unused or to violate Mother Earth by washing away her soil (Ford 1985:14-15). Community organizations controlled irrigation water (Cleveland et al. 1995:3). Prior to European contact, the Zuni territory included 15.2 million acres, but by 1935 the reservation included only 340,000 acres. Grazing, plant collecting, hunting and other resource use traditionally occurred freely on all the uncultivated land within the Zuni territory (Cleveland et al. 2005:7-8).

Zuni land management practices for crops, which were primarily used for domestic consumption and rituals, were traditionally oriented around soil type and water control. Loam (*helvalo:we*) was ideally suited to corn production. Clay (*hepecha*) was primarily used for wheat and hay. Cultivation of corn on clay is more labor intensive and results in lower yields and greater water runoff than cultivation of corn on loam. Adobe, the thickest and least workable soil, was rarely used for crop production. The Zuni traditionally used digging sticks for planting to minimize soil disturbance and moisture loss (Ford 1985).

Zuni water management practices varied based on soil type and topography. Rainfall farming (*kwakowtome* or *e'amakwinishe' make deachinen*) consisted of three general production practices (Ford 1999):

(1) **Dry farming** was undertaken on flat fields and relied on natural rainfall. Management practices were employed only to limit runoff.
(2) **Runoff farming** involved slowing water as it ran down slopes and distributing it across fields with a series of temporary check dams constructed from soil or other organic materials, such as brush and logs.
(3) **Flood-water farming** involved using brush, earth, or stones to divert water from streams or arroyos to flood fields. This method had an additional benefit of depositing silt, which replenished the soil.

Though these classifications are useful in describing Zuni production methods, water management was a dynamic process (Ford 1999:78). For example, a new field located at the mouth of an arroyo might be cultivated using flood-water farming facilitated by a stone dam. The Zunis placed stones in an open array in the steep sections of arroyos. This partial damming slowed the flow of water and resulted in the build-up of sediment behind the stones. At a point down-gradient in the arroyo, where the slope was less steep, water was diverted by ditches dug perpendicularly to the arroyo. This water was released from the ditches and allowed to flow overland to the planted fields, the path of the water directed by herringbone-shaped earthen embankments that helped to achieve a uniform distribution of water to the crops (37-42).[2] The use of stone dams to slow waters in arroyos was also used by the Anasazi, ancestors of the Zuni, to create cultivable plots of silt-rich soil behind the dams, more than 600 years before the time of the Black Rock Dam (Rohn 1963).

The ever-changing nature of Zuni water management practices implied that dams, canals, and other water-spreading techniques were temporary and significant labor was required each year to construct or repair needed structures. The Zuni mitigated the risk of crop failure due to uncertain rainfall by planting a large number of small fields to different crops and by using a variety of farming practices on those fields.

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[2] Unless otherwise indicated, all references are from Ford (1985), with specific page numbers in parentheses.

In some instances, the Zuni used irrigation to supply water for crop production. However, irrigation farming comprised a very small portion of total Zuni agriculture. When canals were used to deliver water to fields, Zuni tradition called for the farmer farthest from the source (at the end of the canal) to divert water to his fields, followed by his upstream neighbor, and so on, working backward to the source (Ford 1985).

In addition to crops, the Zuni grazed some animals, primarily sheep, on open lands to the south and east of the Pueblo. In the event that livestock wandered into a farmer's field and caused damage, the Zuni tribe held the livestock owner responsible for the damage, requiring him to provide compensation to the farmer. Zuni men frequently "brushed up" grazing areas by manually installing brush and other woody materials in the mouths of eroding arroyos, limiting erosion-related damage to adjacent grazing areas.

U.S. water management practices were shaped in large part by the arguments of John Wesley Powell (1879). Powell believed that most western lands were unsuitable for agricultural production without government intervention to provide water for irrigation. Instead of tailoring production practices to water availability, U.S. water systems capture precipitation and snowmelt in the spring and store that water in reservoirs for use throughout the summer and fall, or at times when there is little precipitation to provide the water needed for crop growth. That water is allocated to individuals in the priority order of when individuals first claimed water for use ("first in time, first in right"). If there is not enough water to go around, those who claimed water for use later in time will not receive their allocation for all or part of the year.

The Zuni Irrigation Project resulted in the construction of dams behind which water would be stored as well as a system of canals to deliver that water to farmers throughout the year. It was believed that "the establishment of the Black Rock Reservoir, with an irrigation system, would work wonders among [the Zuni] in a few years" (Ford 1985:54). In general, dams can prove beneficial, including increasing and stabilizing agricultural yields across years and mitigating flood hazards due to peak water runoff events.

In 1900, prior to the construction of the Black Rock Dam, Zuni agriculture outstripped that of any other tribe in the region in terms of yield (96). After the construction of the Black Rock Dam, livestock grazing was restricted to the reservation, as the U.S. government issued property rights for surrounding lands that had previously been used for open grazing. Fencing the reservation resulted in serious overgrazing because the carrying capacity of the land was immediately exceeded by existing livestock (136), and the abandonment of surrounding grazing lands led to severe erosion because of a lack of "brush-up" maintenance (123). Within the reservation, property rights for parcels of land were allocated to individual Zuni under the General Allotment Act of 1887. The Zuni were forced to abandon tributary valleys in which they traditionally produced corn, beans, squash, and melons. Crop production was instead moved onto previously uncultivated clay soils serviced by canals in the Irrigation Project. The build-up of silt behind the Black Rock Dam diminished the ability of the dam to mitigate flood hazards and provide a consistent water supply. At present "No Zuni farmer can support a family if he has to depend upon the Zuni Irrigation Project and Black Rock reservoir for water" (Ford 1985:150). Today, the Zuni are primarily employed in a cash economy based on livestock production and jewelry making.

An Aside on Market Failures

*In a **perfectly competitive** setting, a free market efficiently allocates goods and services across individuals. By **efficiency**, economists mean that the allocation of goods and services cannot be reorganized so that at least one individual is made better off, while no one else is made worse off. However, a number of assumptions must hold for a market to be perfectly competitive. It must be the case that (1) there are a large number of buyers and sellers, (2) the good is homogeneous, (3) there are no*

barriers to exit or entry, (4) there are zero transactions costs, (5) there is perfect and symmetric information, (6) firms do not experience increasing returns to scale, and (7) property rights for the good are well-defined.
When any of these assumptions do not hold, a free market will not generally arrive at an efficient outcome. This is what economists refer to as a ***market failure****. Market failures often arise in the following situations:*

- *There are few buyers and/or sellers, which can occur when an industry exhibits increasing returns to scale. Increasing returns to scale can lead to a* ***natural monopoly*** *in which it is most efficient for a single firm to sell a good because the fixed costs required to enter the industry are high. An example is public utilities. The cost of installing utility infrastructure like electric or water lines is high enough that it forms a barrier to entry.*
- *Information asymmetries exist, i.e. sellers have more information than buyers or vice versa. This occurs in the auto insurance industry, where buyers of insurance know much more about their driving habits than the insurance company. The insurance company must assess the risk of insuring various types of individuals, but cannot know whether any one individual is a high-risk or low-risk customer.*
- ***Externalities*** *arise because one individual's decisions affect the well-being of other individuals who have no input into the decision-making process. An example is when the production decisions of a manufacturing firm produce pollution, influencing air quality and the well-being of surrounding households. The firm does not take into account the* ***social costs*** *of its manufacturing activity, in this case any of the costs of air pollution borne by surrounding households.*
- *The good is a* ***public good****, or one which is non-excludable and non-rival. Non-excludable implies that no one can be excluded from consuming a good; non-rival implies that one individual's consumption of the good does not detract from another individual's ability to enjoy that good. Examples of public goods include national defense and knowledge. For these goods, property rights that define who can sell and who can consume a quantity of a good are impossible to define.*

Neoclassical economic theory suggests that in the event of a market failure, government intervention in the form of policy to regulate the allocation of goods across individuals can improve social welfare by ensuring an efficient outcome.

Discussion Questions:

1. Compare and contrast the Zuni method of land and water management with that of the U.S. government. Describe the economic advantages and disadvantages of each.

2. What economic argument(s) might the U.S. government have used to justify the construction of the Zuni Irrigation Project? Is there a market failure (or multiple market failures) that might result in an inefficient allocation of water across individual irrigators had the U.S. not constructed the Project? Did the Zuni Irrigation Project effectively correct those market failures?

3. Neoclassical economic theory holds that well-defined and complete property rights are necessary to achieve an efficient outcome in a free market. What were the effects on Zuni culture of enforcing private property rights for land and water? How do you reconcile this outcome with neoclassical economic theory?

Part 3. Understanding the Multiple Dimensions of the Zuni Case

After all that work, Judith really had to hand it to herself. How many people could claim to have such a comprehensive understanding of this case? Certainly not that economist she deposed! His testimony was so dry, her eyes began to droop even thinking about it. And one-sided. Forget the 10,000-foot view. This guy's was more like the 10-foot view! But she had to admit that it wasn't until she heard testimony from so many different expert witnesses that she really began to appreciate the complexity of the problem. How would the court find a solution that took into account the cultural, economic, and environmental aspects of the Zuni case? She glanced again at her cell phone just as the judge entered his chambers, his mouth set in a hard line, giving away nothing.

In your mixed expert witness teams, combine your knowledge from Part 2 to discuss the following questions. Designate a note-taker and be prepared to present a few of the points made in your discussion to the class.

1. List physical changes to the land and water on the Zuni Reservation, comparing post-U.S. government intervention to pre-U.S. government intervention.

2. List social and economic changes (and non-changes) to the Zuni people, including both those enumerated in the documents, and those changes you reason may have occurred.

3. What "solutions" can you propose for remedying the agricultural and water problems the modern Zuni now face that stemmed from U.S. government intervention in Zuni traditional land and water management?

Handout 4. A Resolution to the Zuni Case?

The dam constructed at Black Rock in 1906 proved to be problematic at multiple levels, all of which adversely impacted the Zuni people for many years to come. The reservoir capacity was cut by half by sediment deposition ("silting") in just the first ten years of operation (Dodge 2008:95). Land policies imposed by the U.S. government resulted in major declines in farmed/grazed/collected acreage available to the Zuni during the period from about 1850 to 1990.

In 1981, the economically devastated Zuni tribe brought legal suit against the U.S. government in the United States Claims Court. After many years of legal struggle, an out-of-court settlement resulted in federal legislation passed by the 101st Congress and signed by the President in 1990. The "Zuni Land Conservation Act of 1990" (Public Law 101-486) called for the Secretary of the Interior and the Zuni Indian Tribe to jointly formulate a Zuni resource development plan for the Zuni Indian Reservation (U.S. Congress 1990). The legislative mandate stressed sustainable development of renewable resources and a program of watershed rehabilitation (Dodge 2008:181).

The law stipulated that all legal expenses incurred by the tribe be covered, and that there be established a $25 million fund for implementation of conservation and rehabilitation efforts. The Zuni Conservation Project (ZCP) continues to this day as part of the Pueblo of Zuni governance structure, and its work has addressed both the (1) engineering infrastructure and (2) land and water resources.

Some of the engineering improvements in the 1990s following the passage of PL 101-486 were:

- major dredging operations to remove sediments from the reservoir (Dodge 2008:181);
- modifications to enhance the performance of the spillway (such as the fusegates pictured below; Gannett Fleming 2002); [3] and
- installation of a flood warning system to reduce the potential for loss of life from failure or overtopping of the dam (Sutron Corp. 2006).

Fusegates Installed at the Black Rock Dam

Photo source: Gannett Fleming (2002); reproduced with the permission of Gannett Fleming, Inc.

[3] Fusegates are adjustable gates that can "increase both spillway capacity and reservoir storage" at a lower cost than heightening a dam (Afshar and Takbiri 2009; Falvey and Treille 1995:512).

The ZCP has integrated traditional tribal practices and scientific study of the soils and landforms of the region. A 2011 research study using this integrated approach noted (emphasis in bold italics by us):

> … soil degradation is the most common outcome of agriculture on a world-wide basis (especially that caused by accelerated erosion, nutrient loss, and salinization), and similar outcomes are represented in the Southwest. Unlike many other parts of the world, it is interesting to note that numerous examples of ***soil enhancement*** are represented in agroecosystems of the Southwest. The American Southwest, with its long agricultural history and wide range of systems, environments, and effects, holds valuable evidence and lessons on soil and landscape change. (Homburg and Sandor 2011:152)

The soil was improved by traditional agricultural practices! Rather than eroding, the soil layer was actually thickening.

The Homburg and Sandor (2011) study fits well within the relatively new, transdisciplinary field of "agroecology," which attempts to apply the principles of ecology to the design and management of agricultural systems—past and present. The agroecological approach is holistic and includes consideration of traditional knowledge, alternative agriculture, and local food system experiences. It links ecology and other sciences with fields such as economics and anthropology, and the knowledge that it provides is part of our toolkit for building a sustainable future.

The Zuni live in a region of the world where limited water is a key factor in how lives are lived. Lack of water is a reality presently shared by over two billion people around the world — about a third of our population. We live on a Blue Planet, but drylands make up more than 40% of the land surface. The United Nations has warned "Under the climate change scenario, nearly half of the world's population in 2030 will be living in areas of high water stress. In some arid and semi-arid areas, it will displace up to between 24 million and 700 million people" (United Nations 2013). One of the great challenges of the coming decades will be how to feed more people, on less land, with less water: agroecological thinking will be a key component of that solution.

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Glossary

adobe	Clayey soil, or a form of construction in which a wooden structure is coated with such soil.
arroyo	A channel with intermittent water.
geomorphologist	A geologist who studies landforms and how they developed.
matrilineal	A society that traces descent through the mother's lineage.
matrilocal	A society in which a newly married couple sets up their household with the wife's family.
pinyon	A type of pine tree with edible nuts called pine nuts.
pueblo	Apartment-like adobe structures where people live. A large pueblo may encompass the entire town.
worldview	A culture's hidden viewpoint that structures that society's perception and understanding of life and the world around them. It is often taken for granted rather than explicitly taught or discussed.

References Cited

Afshar, Abbas and Zeinab Takbiri
2009 Optimal Design and Operation of Fuse-gates Considering Water Loss due to Gates Tilting. In *World Environmental and Water Resources Congress 2009*: *Great Rivers*, edited by Steve Starrett, pp. 1-8. American Society of Civil Engineers. doi: 10.1061/41036(342)309.

Cleveland, David A., Fred Bowannie, Jr., Donald F. Eriacho, Andrew Laahty, and Eric Perramond
1995 Zuni Farming and United States Government Policy: The Politics of Biological and Cultural Diversity in Agriculture. *Culture and Human Values* 12:2-18.

Dodge, William A.
2008 *Black Rock: A Zuni Cultural Landscape and the Meaning of Place*. University Press of Mississippi.

Ethnologue
2013 World Languages. In *Ethnologue: Languages of the World*. Retrieved 13 September 2013 from http://www.ethnologue.com/world

Falvey, Henry T. and Philippe Treille
1995 Hydraulics and Design of Fusegates. *Journal of Hydraulic Engineering* 121:512-518.

Ferguson, Thomas J.
1996 *Historic Zuni Architecture and Society: An Archaeological Application of Space Syntax*. Anthropological Papers No. 60. University of Arizona Press, Tucson.

Ford, Richard I.
1985 *Zuni Land Use and Damage to Trust Land*. Expert Testimony Submitted to the United States Claims Court as Evidence in the Case Zuni Indian Tribe v. United States, Exhibit 7000, Docket 327-81L (Ct. Cl., filed May 12, 1981). Retrieved 11 September 2013 from http://content.lib.utah.edu/cdm/ref/collection/wwdl-neh/id/11244
1999 Ethnoecology Serving the Community: A Case Study from Zuni Pueblo, New Mexico. In *Ethnoecology: Situated Knowledge/Located Lives*, edited by Virginia D. Nazarea, pp. 71-87. University of Arizona Press, Tucson.
Gannett Fleming
2002 Black Rock Dam Receives Award. Gannett Fleming Newsroom. Retrieved 11 September 2013 from http://www.gannettfleming.com/newsroom/2002/blackrock.htm
Gellis, Allen C.
1998 *Characterization and Evaluation of Channel and Hillslope Erosion on the Zuni Indian Reservation, New Mexico, 1992-95*. Prepared in Cooperation with the Pueblo of Zuni. Water-Resources Investigations Report 97-4281, U.S. Geological Survey, Albuquerque, NM. Retrieved 11 September 2013 from http://pubs.er.usgs.gov/publication/wri974281
Hart, E. Richard, editor
1995 *Zuni and the Courts*. University Press of Kansas, Lawrence.
Helms, Douglas
2008 *Hugh Hammond Bennett and the Creation of the Soil Erosion Service.* Historical Insights Number 8, U.S. Department of Agriculture, Natural Resources Conservation Service, Washington, DC. Retrieved 24 September 2013 from http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_021210.pdf
Homburg, Jeffrey A. and Jonathan A. Sandor
2011 Anthropogenic Effects on Soil Quality of Ancient Agricultural Systems of the American Southwest. *Catena* 85:144-154.
James, Steven R.
1997 Change and Continuity in Western Pueblo Households during the Historic Period in the American Southwest. *World Archaeology* 28(3):429-456.
Nabhan, Gary Paul, Patrick Pynes, and Tony Joe
2002 Safeguarding Species, Languages, and Cultures in the Time of Diversity Loss: From the Colorado Plateau to Global Hotspots. *Annals of the Missouri Botanical Garden* 89:164-175.
NCDC (National Climatic Data Center)
2013 Climate at a Glance: Time Series, U.S. Retrieved 17 September 2013 from http://www.ncdc.noaa.gov/cag/time-series/us
Olesko, Kathryn M.
2010 Water in the Prussian Frontier. Lecture presented at the Maryland Colloquium on the History of Technology, Science, and Environment, September 9. University of Maryland, College Park, MD.
Pedosphere.ca
2011-2012 *Soil Texture Triangle Hydraulic Properties Calculator (Can.)*. Pedosphere.ca Learning Resources. Retrieved 13 September 2013 from http://www.pedosphere.ca/resources/texture/triangle.cfm
Powell, John W.

1879 *Report on the Lands of the Arid Region of the United States with a More Detailed Account of the Land of Utah with Maps*. United States Geological Survey Unnumbered Series Monograph. Government Printing Office, Washington, D.C. Retrieved 12 September 2013 from http://pubs.er.usgs.gov/publication/70039240

Rohn, Arthur H.
1963 Prehistoric Soil and Water Conservation on Chapin Mesa, Southwestern Colorado. *American Antiquity* 28(4):441-455.

Sutron Corp.
2006 Pueblo of Zuni, Black Rock Dam early warning system. Retrieved July 25, 2013 from http://www.sutron.com/pdfs/FloodWarningSystems.pdf

United Nations
2013 Why Now? United Nations Decade for Deserts and the Fight against Desertification. Retrieved 11 September 2013 from http://www.un.org/en/events/desertificationday/index.shtml

U.S. Census Bureau
2013 Zuni Tribe of the Zuni Reservation, generated by Gail E. Wagner, using American FactFinder2, 13 September 2013 from http://factfinder2.census.gov/

U.S. Congress
1990 Public Law 101-486. An Act to Authorize Appropriation of Funds to the Zuni Indian Tribe for Reservation Land Conservation, and for Other Purposes. ("Zuni Land Conservation Act of 1990") U.S. Government Printing Office, Washington, D.C.

USDA-NRCS (U.S. Department of Agriculture, Natural Resources Conservation Service)
2005 *Soil Survey of McKinley County Area, New Mexico, McKinley County and Parts of Cibola and San Juan Counties*. Retrieved 13 September 2013 from http://soils.usda.gov/survey/online_surveys/new_mexico/