Applied Energy 88 (2011) 3492–3498

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

# Water management policies for the algal biofuel sector in the Southwestern United States

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ARTICLE INFO

*Article history:*
Received 3 August 2010
Received in revised form 23 September 2010
Accepted 14 October 2010
Available online 12 November 2010

*Keywords:*
Algal biofuel
Aquifers
Bioenergy
EROWI
Water footprint
Water management policies

ABSTRACT

Algal biorefinery-based integrated industrial ecology has received increased attention as a sustainable way of producing biofuel, food, high value products and feed ingredients in the Southwestern United States (US). However, these regions already face serious freshwater supply issues. Hence, new policies and regulations for water management and use is a high priority for the sustainable development of an algal biofuel sector to meet liquid fuel needs in the US without hampering the regional hydrologic pattern.



## 1. Introduction

Algal biomass production offers several advantages over conventional terrestrial biofuel feedstocks. Algae offer significantly higher biomass and lipid yields per acre per year [1], economic use and recovery of waste nutrients [2], use of non-potable water such as saline, brackish, industrial or municipal waste water, productive use of non-crop lands (desert, arid and semi-arid land) [3] and capture of $CO_2$ from power-plant flue gas, cement or other manufacturing plants, breweries or other carbon sources [4,5]. These positive sustainability indices have attracted substantial research investments from federal government, private investors and energy industries into this sector as a sustainable way of producing next generation biofuel, food, and high value products [6,7]. The recent National Algal Technology Road Map by United States Department of Energy identified Southwestern states are optimal for future algal biofuel sector [8]. Similarly, a ‘renewable energy corridor’ rich in the multiple energy sources needed for algal biofuel production via the deployment of Integrated Renewable Energy Parks has been envisioned in the Southwestern (SW) US [9–11]. This corridor, comprised mainly of regions of New Mexico, Arizona, and Colorado, is poised as an optimal region for algal biomass generation because of the availability of the necessary natural resources such as sunlight, an optimum ambient temperature, cheap arid land and saline water [6,8]; however, some of these regions face major freshwater issues.

## 2. Water resources in Southwestern United States

The upper and lower Colorado basin and the Rio Grande River basin are the main surface water resources in the corridor area. The Colorado River and its watershed (242,900 square miles) is the major source of water for irrigation, drinking, and other uses by people living in the arid SW States [12]. Since the completion of several dams (e.g., Glen Canyon Dam, Hoover Dam, Imperial Dam), the majority of the river has been diverted for agricultural irrigation and municipal water supply. Several cities have aqueducts leading all the way back to the Colorado River. Similarly, the Rio Grande River and basin mainly provides surface water resources to regions of lower Colorado and to the entire state of New Mexico. Several fresh and saline ground water resources (~5 billion acre-feet of brine water) are contained within several aquifers in this corridor. Although not complete list a brief summary of the major fresh and saline aquifers in the SW US is listed in Table 1. The surface and ground water resources are already being used extensively in this corridor region.

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doi:10.1016/j.apenergy.2010.10.024

**Table 1**
Major fresh and saline aquifer in Southwestern United States (tabulated using the information from Refs. [51–53]).

| Aquifer | Geographic region and characteristics |
|---|---|
| Albuquerque Basin | The Albuquerque Basin covers about 2100 square miles of central New Mexico<br>The basin was formed by tectonic events in Pennsylvanian–Permian time, Jurassic-Cretaceous time, late Cretaceous-Tertiary time, and events in Oligocene-Recent time associated with opening of the Rio Grande Rift. Recharge enters the Santa Fe Group sediments by surface water infiltration, mountain front recharge, and as ground water flow across the northern boundary of the Albuquerque Basin |
| San Juan Basin | The San Juan Basin covers about 15,000–20,000 square miles of New Mexico, Colorado, Arizona, and Utah. All the major aquifers in the basin contain areas of freshwater. All major aquifers in the basin, with the exception of the aquifer contained in the Gallup Sandstone, also contain saline water. The San Juan Basin contains rocks of Precambrian through Quaternary age. It measures roughly 100 miles long in the north–south direction and 90 miles wide |
| Roswell Basin | The legal boundary of the Roswell Ground water Basin includes 10,799 square miles of southeastern New Mexico. Roswell Artesian Basin is located in the lower Pecos Valley of southeastern New Mexico, on the northern fringe of the Chihuahua Desert. Studies have documented the occurrence of saline ground water in the artesian aquifer [54] |
| Capitan Aquifer | Located in west Texas and southeast New Mexico. Ancient reef which formed around the margins of the Delaware Basin in the Permian period. Regionally ground water flow is to the east; in the Capitan it was towards the north |
| Estancia Basin | The Estancia Basin covers about 1500 square miles of central New Mexico The basin was formed by tectonic events in late Pennsylvanian to Permian time, late Cretaceous to Eocene time, and Oligocene to Holocene time. The most recent tectonic event is associated with formation of the Rio Grande Rift |
| Tularosa Basin | The Tularosa and Salt Basins together cover approximately 7750 square miles of south central New Mexico Though hydrologically different, their proximity suggests they be discussed together as a potential source of saline ground water. The Tularosa Basin covers approximately 6500 square miles of south central New Mexico. Hydrologically, the Tularosa Basin is a closed basin; no streams flow out |
| Salt Basin | The Salt Basin is located in the Trans-Pecos region of West Texas. It forms a valley that extends from just north of the New Mexico border in Hudspeth and Culberson Counties along a southeastern trend through western Jeff Davis County, where it ends in the northwest portion of Presidio County. The Salt Basin is approximately 140 miles long and 25 miles across at its widest point |
| Mesilla–Hueco Basin | The Mesilla Basin aquifer system is an extensive intermontane aquifer system which extends from southern New Mexico to Northern Mexico. The aquifer's boundaries are comprised of the Organ, San Augustine, Franklin, Portillo, Robledo, Dona Ana, and Sierra de Cristo Mountains. The Rio Grande traverses the Mesilla Basin for 60 miles and exits into the Hueco Bolson are shared by New Mexico, Texas and Mexico, and provide nearly all municipal and industrial needs. Ground water from the Hueco and Mesilla are being "mined" and saline water from adjacent saline bearing sands is encroaching upon higher quality ground water |
| Seymour Aquifer | The Seymour Aquifer consists mainly of the scattered erosional remnants of the Seymour Formation of Pleistocene age. The aquifer has been referred to in the literature as the "north-central Texas alluvial aquifers" because it is in 22 separate areas of alluvium in parts of 20 Texas counties in the upper Red and upper Brazos River Basins. About 4.5 million acre-feet of fresh to slightly saline water was estimated to be in storage in the Seymour Aquifer in 1974. About 75% of this water, or about 3.4 million acre-feet, was estimated to be recoverable |
| Edwards–Trinity Aquifer | Edwards-Trinity Aquifer system is in carbonate and clastic rocks of Cretaceous age in a 77,000-square-mile area that extends from southeastern Oklahoma to western Texas. The aquifer system consists of three complexly interrelated aquifers-the Edwards-Trinity, the Edwards, and the Trinity Aquifer |
| High Plains Aquifer (Ogallala Aquifer) | The High Plains Aquifer underlies an area of about 174,000 square miles that extends through parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming. The aquifer is the principal source of water in one of the major agricultural areas of the United States. About 20% of the Nation's irrigated agricultural land overlies the High Plains Aquifer, and about 30% of the ground water used for irrigation in the Nation is withdrawn from the High Plains Aquifer. In 1980, about 17,800,000 acre-feet of water was withdrawn from the aquifer to irrigate about 13,000,000 acres of cropland. The boundary of the aquifer approximates the boundary of the Great Plains Physiographic Province. The province is characterized by a flat to gently rolling land surface and moderate precipitation |
| The Cenozoic Pecos Alluvium Aquifer | The Cenozoic Pecos Alluvium Aquifer, located in the upper part of the Pecos River<br><br>Valley of west Texas, provides water to parts of Andrews, Crane, Ector, Loving, Pecos, Reeves, Upton, Ward, and Winkler counties. The aquifer is the principal source of water for irrigation in Reeves and northwestern Pecos counties, and for industrial, power generation, and public supply uses elsewhere. A significant amount of water is exported to cities east of the area |
| Dockum Aquifer | The Dockum Group of Triassic age underlies much of the Ogallala Formation of the High Plains area of Texas and New Mexico, the northern part of the Edwards Plateau, and the eastern part of the Cenozoic Pecos Alluvium. Where exposed east of the High Plains caprock and in the Canadian River Basin, the land surface takes on a reddish color. In the subsurface, the Dockum is commonly referred to as the "red bed." The primary water-bearing zone in the formation, the Santa Rosa, consists of up to 700 ft of sand and conglomerate interbedded with layers of silt and shale |
| Denver Aquifer | The Denver Aquifer covers an area of approximately 3500 square miles and ranges in thickness from 800 to 1000 feet, a considerably larger footprint than the Dawson. The maximum depth of the aquifer is approximately 1300 feet. The Denver Aquifer is comprised of both unconfined and confined layers depending on your location within its boundary (see diagram below). The aquifer is composed of interbedded shale, claystone, siltstone and sandstone pockets. There is an estimated annual withdrawal of over 72,000 acre-feet of water from approximately 800 high-capacity wells |
| Arapahoe Aquifer | The Arapahoe Aquifer encompasses approximately 4700 square miles and ranges in thickness from zero to 400 feet. Its maximum depth is approximately 1700 feet. The aquifer is comprised of an interbedded sequence of conglomerate, sandstone, siltstone and shale. Municipal wells drilled in this aquifer yield up to 700-gallons per minute. The Arapahoe contains over 1000 high-capacity wells with an estimated total annual withdrawal of more than 168,000 acre-feet |
| Dawson Aquifer | The closest aquifer to the ground surface in Douglas County; the Dawson covers a surface area of approximately 1400 square miles in the Denver Basin. Its thickness ranges between 400 and 1200 feet and reaches a maximum depth of approximately 600 feet. The Dawson is the least extensive aquifer of the Denver Basin system but provides for some of the higher volume pumping rates. The Dawson is an entirely unconfined aquifer and is composed of conglomerates (individual stones that have become cemented together) and coarse-grained sandstones with minor amounts of interbedded clay and clay shale. Due to its relative shallowness, the aquifer is commonly tapped by domestic wells. The Dawson Aquifer has approximately 19,000 permitted wells that withdraw over 30,000 acre-feet per year, at upwards of 300 gallons per minute |
| Range and Basin Aquifers | The Basin and Range Aquifers and the Rio Grande aquifer system generally consist of unconsolidated gravel, sand, silt, and clay, or partly consolidated sedimentary or volcanic materials. However, most valleys in the Range and Basin Aquifers are interconnected, and ground water moves from valley to valley through the interconnected network of aquifers. The Basin and Range aquifers extend westward into California, Nevada, Oregon, and Idaho; the Rio Grande aquifer system extends southward into Texas and Mexico |