

Featured Lake Abert, OR

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Salt Lake in the High Desert

Among the curiosities found in G.E. Hutchinson's classic, four-volume series, *A Treatise on Limnology*, the pen-and-ink sketch on page 15 of Volume I is perhaps most intriguing. The sketch, credited to I.C. Russell (1895), depicts Oregon's Lake Abert* lying on a tilted fault block in a region of the state called the high desert country. The caption refers to Lake Abert as a "beautiful example of a lake against a fault scarp." Hutchinson's expressive description befits the sketch, given that it is the only aesthetic rendition of a lake in his entire four-volume series. Russell was more pragmatic, as Hutchinson (1957) noted, calling Lake Abert the "finest example" of a lake of this type in the basin-and-range topography of the Great Basin (Figure 1).

Native Americans lived along the shores of Lake Abert thousands of years before white men arrived in North America. Although the lake was probably visited by trappers and other nonindigenous humans, the first recorded visit was made in October 1832 by a detachment of U.S. Army soldiers who called the lake "Salt Lake." In December 1843, Captain John C. Fremont of the U.S. Army's Topographical Engineers Corps "discovered" the lake while leading troops and horse-drawn cannons in heavy snow en route to California. In a spirit of magnanimity, Fremont named the lake for his commander, Colonel J.J. Abert. [Author's Note: Ironically, a double-deck,

*Although Hutchinson (1957) referred to the lake as "Abert Lake," the correct name as listed in *McArthur's Oregon Geographic Names* (1992) and in the U.S. Geological Survey's official list of U.S. geographic names is "Lake Abert."



Figure 1. Photorealistic imagery of lakes in the Oregon high desert country. Image created from mathematical simulations of satellite data interpreted by computer calculations. Image courtesy of Dr. William Bowen, California Geographical Survey, Roseville, California.

traffic-congested freeway bridge that crosses the Willamette River in Portland, Oregon, is named in honor of Fremont, a man who spent his professional life exploring uncharted and unspoiled lands in the American West.]

Lake Origin and Basin Topography

Lake Abert and neighboring Summer Lake are remnants of pluvial Lake Chewaucan that once covered nearly 500 square miles in south-central Oregon (Figures 2 and 3). Formed during the late Pleistocene Epoch, Lake Chewaucan reached a maximum depth of 375 feet in a basin enclosed by escarpments of uplifted and down-dropped fault blocks

(Allison 1982). The floor of the of the basin, as described by Van Denburgh (1975), consists of "numerous horsts, grabens, tilted fault blocks of spectacular proportion."

Long before Lake Chewaucan existed, however, Lake Abert and Summer Lake occupied grabens, or downthrust troughs on the basin floor. During the Pleistocene, the lakes varied in size in response to cyclic climatic conditions, ranging from cold and dry to warm and wet. Wetter conditions eventually flooded much of the basin.

In the process of creating Lake Chewaucan, rising floodwaters completely inundated the preexisting lakes, Abert

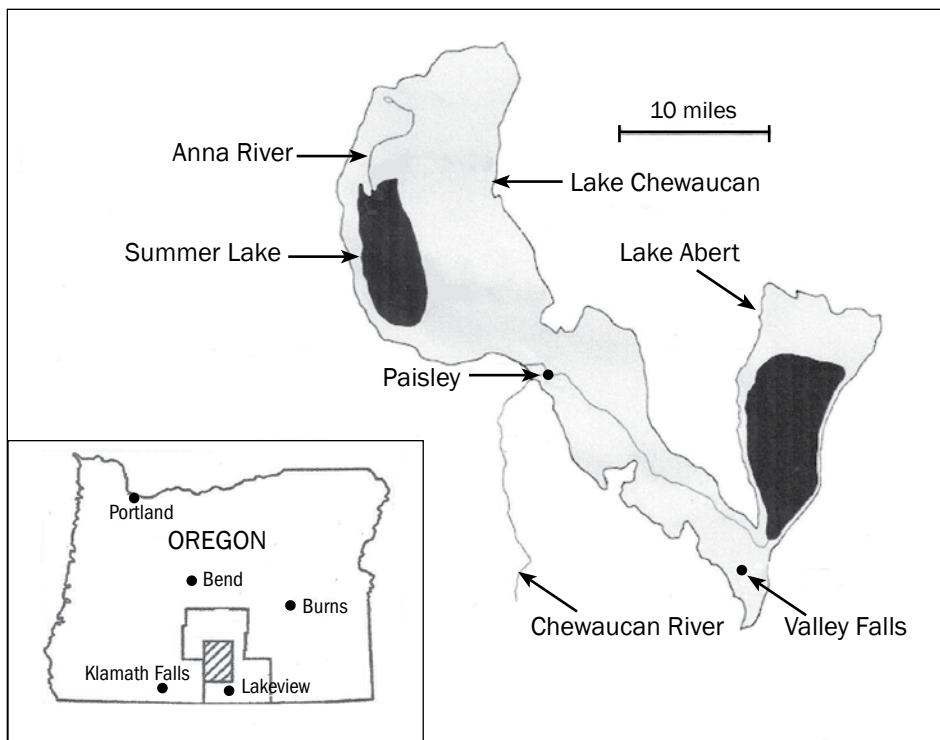


Figure 2. Lake Chewaucan and its remnant lakes, Abert and Summer. Source: Grayson 1993. Cross-hatched rectangle indicates lakes' location in Oregon. Source: Allison 1982.

and Summer. At its maximum size, Chewaucan's surface elevation stood at 4,520 feet above mean sea level (amsl) based on ancient shoreline features, including stranded deposits of beach gravels and wave-cut terraces, cliffs, and caves (Allison 1982). After a period of unknown duration, the lake began to recede in response to drier climatic conditions. By the end of its drawdown, roughly 10,000 years ago (Allison 1982), the lake had diminished to four smaller, interconnected basins: Summer Lake, Upper Chewaucan Marsh, Lower Chewaucan Marsh, and Lake Abert (Figure 3).

Overlooking the basins are impressive, sharply defined fault-block escarpments. Chief among these are (1) Winter Ridge, a 3,000-foot-high scarp that borders the west shoreline of Summer Lake; (2) the Coglan Buttes fault block, featuring a highly indented fault-line that extends for about 20 miles along the eastern edge of the Chewaucan marshes, and rises to a maximum height of about 2,000 feet above the basin floor; and (3) Abert Rim, a precipitous escarpment that rises to 2,500 feet or more along the entire east shoreline of Lake Abert (Figures 3 and 4).

Lake Morphometry as a Function of Hydrology

Lake Abert and its watershed occupy a closed basin (endorheic) covering about 860 square miles. The lake – situated on a playa in an arid climate where precipitation averages 12 inches annually – has a history of extreme lake-level fluctuations, ranging from complete dryness to a maximum-recorded surface elevation of 4,260.48 feet (amsl). At this elevation, recorded on June 22, 1958, the lake covered approximately 64 square miles and had a maximum depth of about 16 feet (amsl). At its lowest-recorded surface elevation (4,246.60 feet, amsl), obtained on November 11, 1950, the lake covered 22 square miles and was only two feet deep (Table 1).

When Fremont visited Lake Abert in 1843, its surface elevation was about 4,256 feet (amsl). This elevation, representing the first lake-level determination, was inferred from a sketch that Fremont had drawn of the lake. Accordingly, the sketch shows the lake covering beaches that were exposed in 1915 when surface elevation was about two feet lower at 4,254.2 feet (amsl).

Beginning in the 1860s, when surface elevations were first observed on a routine

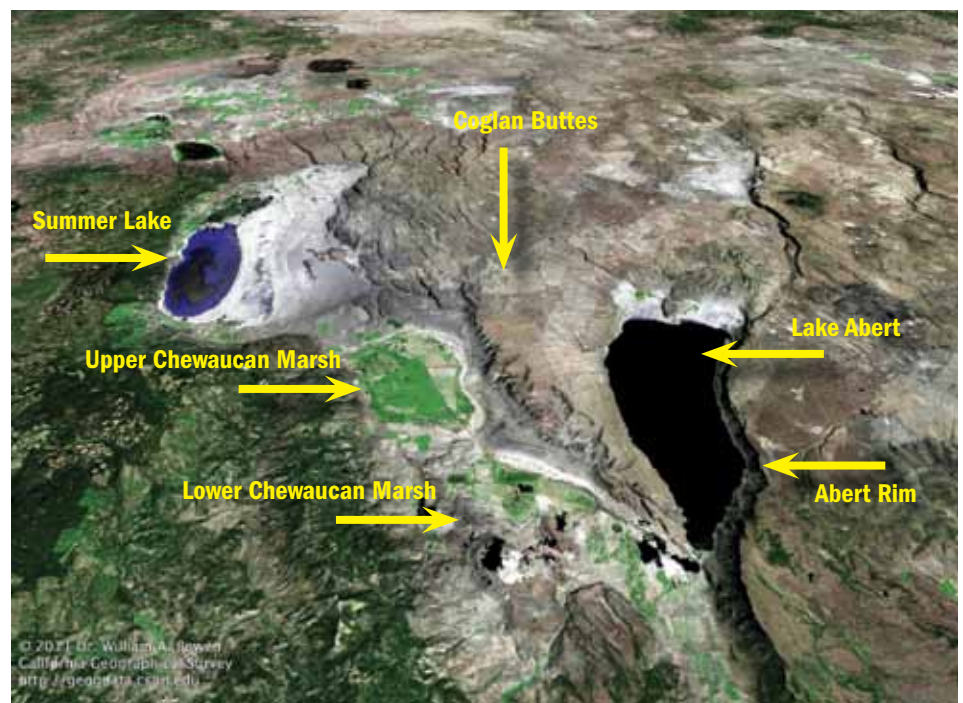


Figure 3. Photorealistic imagery of Lake Chewaucan's four remnant basins. Image created from mathematical simulations of satellite data interpreted by computer calculations. Image courtesy of Dr. William Bowen, California Geographical Survey, Roseville, California.



Figure 4. Abert Rim rises majestically over Lake Abert. Photo taken May 29, 2010 near Poison Creek, about 7.5 miles northeast of the town of Valley Falls, Oregon. Photo by Ron Larson.

Table 1. Lake Abert Morphometry for the Highest- and Lowest-recorded Lake Surface Elevations, 1916-1965.

	<i>Highest</i>	<i>Lowest</i>
Surface elevation, feet above msl	4,260.5 ¹	4,246.6 ²
Surface area, square miles	64	22
Volume, acre-feet	520,000	15,000
Depth, maximum, feet ³	16	2
Length, miles ³	16	3
Width, miles ³	6	1.1

¹ Keister (1992) reported that the “maximum level during the past 100 years was about 4,462 feet above sea level during the summer of 1984.” At that elevation, the lake would have covered 65 square miles and contained 560,000 acre-feet of water.

² Van Denburgh (1975) indicated that the lake’s surface elevation actually fell to 4,245 feet (amsl), probably during the drought years. Approaching dryness at that point, the lake would have covered 12 square miles and contained only 4,000 acre-feet of water.

³ Estimated values.

Source: Phillips and Van Denburgh (1971); Van Denburgh (1975).

basis, the lake basin contained water every year until 1924 when the basin was dry or nearly dry. The basin remained nearly dry, or completely so, during most years between 1926 and 1937. Wetter conditions have since prevailed, allowing Lake Abert to exist as a perennial body of water, at least to the present. Drier conditions will likely return, once again causing complete

lake-basin desiccation (Phillips and Van Denburgh 1971; Van Denburgh 1975).

As shown in Table 1, lake morphometry can change dramatically in response to fluctuations in surface elevation. A nine-foot drop in elevation between 1998 and 2009 – from elevation 4,257 feet (amsl) in 1998 to elevation 4,248 feet (amsl) in 2009 – reduced the

lake’s area from 61 to 39 square miles and its volume from 358,000 to 54,000 acre-feet (Figure 5).

The broad expanse and extreme flatness of the lake basin allows strong, persistent winds to push lake water for considerable distances well beyond the lake’s normal perimeters (Phillips and Van Denburgh 1971). This phenomenon can alter morphometric features temporarily, such as surface area, mean depth, lake shape, and shore length.

Water Supply and Loss

Water is supplied to Lake Abert almost entirely by the Chewaucan River. The river’s watershed, consisting largely of timbered and mountainous terrain, covers an area of about 500 square miles. Flowing northward from its headwaters in the Fremont-Winema National Forest, the river makes a loop at the northern end of the Chewaucan marshes and continues flowing toward the south end of the lake (Figure 6). As it bends northward again (Figure 6), the river is impounded by an earth-filled dam located within a mile upstream of the lake. [Author’s Note: *Discussion about the dam and its ecological effects on Lake Abert will follow in a later section.*] Below the dam the river flows through several oxbow channels before entering the lake’s south end (Figures 7 and 8).

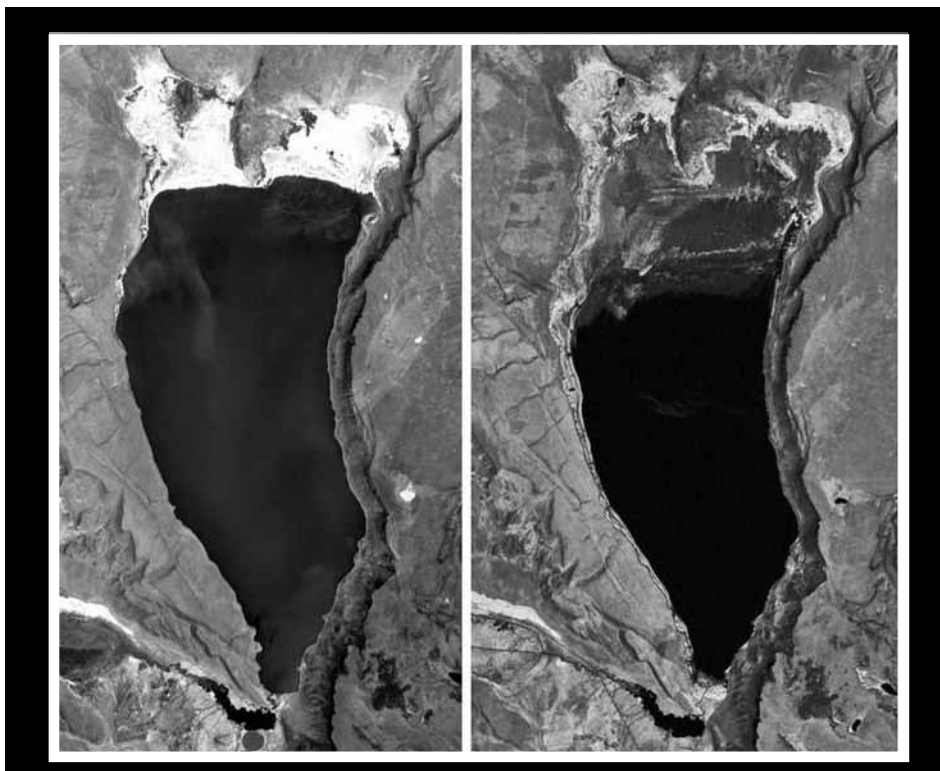


Figure 5. NASA Landsat photograph of Lake Abert. Left-hand photo taken August 27, 1998 when lake's surface elevation stood at 4,257 feet (amsl). Right-hand photo taken September 12, 2009 when elevation was 4,248 feet (amsl). Source: U.S. Geological Survey.

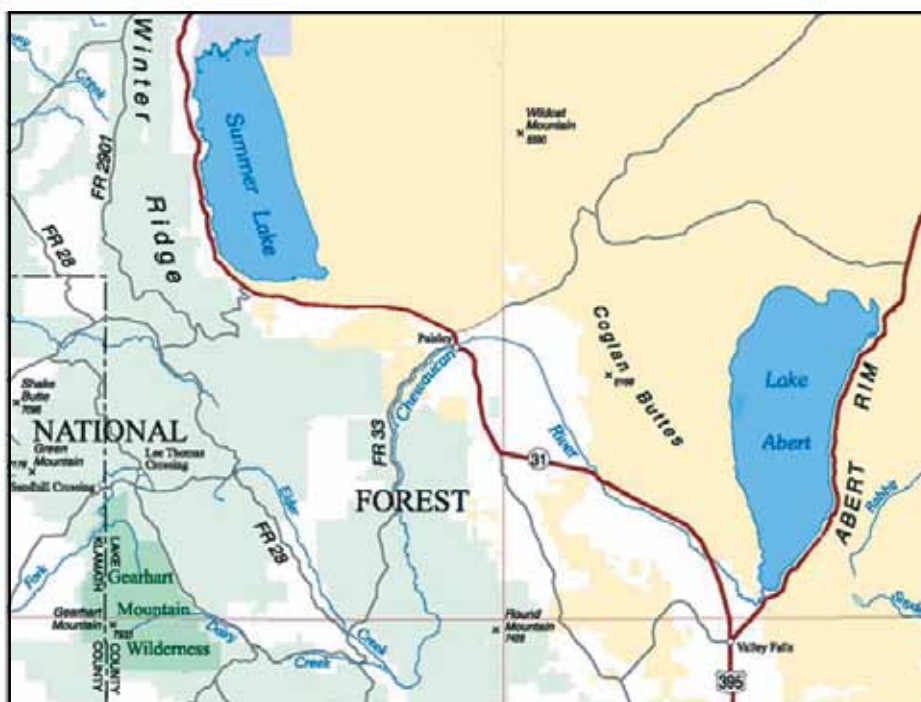


Figure 6. Map of the Chewaucan River drainage basin and the river's entrance to Lake Abert. Source: Fremont-Winema National Forest, U.S. Forest Service, Lakeview, Oregon.

River discharge measured at Paisley, Oregon (refer to Figure 6 for location) averaged 105,100 acre-feet per year between 1912 and 1991. During this

period, total discharge was highest in 1956 when 250,000 acre-feet were recorded. Discharge was lowest in 1924 when unusually dry conditions resulted

in an estimated 18,000 acre-feet produced for the year. Discharge rates averaged 145 cubic feet per second (cfs), with a maximum rate of 6,490 cfs recorded on December 22, 1964 when the Pacific Northwest was being hit with a 500-year flood event. During the winters of 1927 and 1932, however, discharge was so low that *no* flows were reported on two occasions when the river completely froze (Hubbard et al. 1992).

As the river flows away from the Paisley site toward Lake Abert, irrigation withdrawals reduce river discharge substantially. During the period 1916-1965, the river lost roughly 35 percent of its flow-volume (yearly average) between Paisley and the lake, a distance of about 32 river miles. Thus, although the quantity of water measured at Paisley averaged 96,000 acre-feet annually, only about 62,000 acre-feet of this amount reached Lake Abert. When combined with approximately 8,000 acre-feet received from other sources (direct precipitation, seeps, springs, ephemeral streams), the total inflow to Lake Abert averaged about 70,000 acre-feet annually between 1916 and 1965 (Phillips and Van Denburgh 1971; Van Denburgh 1975).

Water is lost perhaps entirely through evaporation since the lake is in a closed basin with no surface outlets. Evaporation removes an average of around 40 inches of lake water per year. Leakage through the basin floor is prevented by a deep layer of fine-grained sediments resembling a hard pan that underlies the basin. The presence of springs and seeps along the shoreline indicates that ground water flows into but not out of the lake. Thousands of years have passed since the lake last overflowed (Phillips and Van Denburgh 1971; Van Denburgh 1975).

Water Chemistry and the Salinity Spectrum

Lake Abert, its waters containing nearly 15 million tons of dissolved solids in 1969, has been described as "the largest landlocked saline water body in the Pacific Northwest" (Phillips and Van Denburgh 1971; Van Denburgh 1975). Among the lake's ionic constituents, sodium comprises about 40 percent of the total ions, followed by chloride (35 percent), and carbonate (22 percent). Calcium and magnesium are barely present, along with other trace elements



Figure 7. Aerial view of the Chewaucan River showing the river entering the Rivers End Reservoir and continuing its flow below the dam toward the south end of Lake Abert. There, the river crosses an exposed salt flat before entering the lake. The three circular patterns along the south side of the reservoir are crop-irrigation plots. Photo taken July 2004. Scale: 5/8 inch=about 1,000 feet. Source: National Agricultural Imagery Program, U.S. Department of Agriculture, Salt Lake City, Utah.



Figure 8. Same aerial view as that shown in Figure 7. In this photo, taken July 2006, river-flows are apparently higher; both above and below the reservoir. In response, the lake's surface elevation was 3-4 feet higher than it was in July 2004 when the lake's shoreline revealed exposed salt flats (see Figure 7). Scale: 5/8 inch=about 1,000 feet. Source: National Agricultural Imagery Program, U.S. Department of Agriculture, Salt Lake City, Utah.

such as cobalt, lead, nickel, molybdenum, and vanadium (Table 2). Calcium is mostly tied up by organic matter and inorganically as CaCO_3 , and magnesium is largely bound up in lake sediments as magnesium silicate (Van Denburgh 1975). Salinity – defined by Kalff (2002) as the sum of ionic compounds dissolved in water – is inversely related to the volume of the lake. In July 1958, for example, lake waters were unusually dilute due to the lake's record-high surface elevation (4,260.5 feet, amsl) and volume (roughly 520,000 acre-feet). Salinity then stood at its record-low concentration of 18.7 g/liter. Conversely, under low-water conditions in July 1939, a salinity concentration of 95 g/liter was

measured, that being a record for the period 1939-1969 (Table 3). Although not measured, salinities greater than 100 g/liter undoubtedly occurred between 1924 and 1937 when severe drought conditions reduced the lake to near dryness (Phillips and Van Denburgh 1971). Since then, considerably higher salinities of 115 and about 180 g/liter have been reported, the former by Keister (1992) and the latter by Herbst (1994) when surface elevations stood at 4,250 feet (amsl) or less.

The salt tonnage in Lake Abert waters nearly doubled between 1939 and 1969, from 8.2 to 14.8 million tons. Although salt is derived from several sources – including the Chewaucan River, precipitation, wind-deposits, and

peripheral springs, seeps, and ephemeral streams – salt is mostly accumulated from lake-bottom sediments, including playa sediments exposed during dry periods. In 1969, in addition to the nearly 15 million tons of salt dissolved in lake waters, the interstitial waters in the upper five feet of sediment contained an estimated 25 to 35 million tons of salt as brine (Van Denburgh 1975).

One process by which salt is transported from sediments into lake waters depends on the concentration gradient along the sediment-water interface. When surface elevations are high, lake waters become less saline due to the dilution effect of the lake's relatively large volume. Under these

Table 2. Lake Abert Water Chemistry.*

	September 7, 1961	July 21, 1939
Surface elevation, feet above msl	4,252.04	4,248.2 (estimate)
Water temperature, 0C	20.0	
pH	9.7	
Specific conductance, micromhos at 25°C	70,200	
Total dissolved solids, g/l (calculated)	55,400	95,000
Sodium	21,900	38,000
Chloride	19,200	28,500
Carbonate	9,290	25,400
Bicarbonate	5,850	
Sulfate	985	1,000
Potassium	716	
Silica	172	
Bromide	95	
Boron	80	
Orthophosphate	78	
Fluoride	7.8	
Calcium	1.4	
Magnesium	0.6	

*Ion concentrations in mg/liter. Only six variables measured in 1939. Trace elements present, but not listed here. Source: Phillips and Van Denburgh (1971).

Table 3. Relationship Between Salinity (Total Dissolved Solids) and Surface Elevation in Lake Abert, 1939-1969.¹

	Elevation, feet (amsl)	Volume (ac-ft X 1,000) ²	TDS (g/liter)
Jul 1939	4,248.2	54	95³
Aug 1952	4,252.7	192	35
Aug 1955	4,252.8	192	40.4
Jul 1958	4,260.5	520	18.73
May 1959	4,258.9	437	21.7
Sept 1961	4,252.0	174	55.4
Sept 1962	4,250.7	141	71
Aug 1963	4,254.5	301	37.5
Jul 1964	4,253.9	245	40
Aug 1966	4,256.2	320	31.4
June 1969	4,255.5	301	35.4

¹ The concentration of total dissolved solids (TDS) is approximately equivalent to salinity (Kalf 2002).

² Approximate values.

³ Maximum and minimum TDS values obtained between 1882 and 1969.

Source: Van Denburgh (1975).

conditions, salt brine migrates upward from the more salt-concentrated sediments across the concentration gradient into the more dilute lake waters: In 1964, approximately 45 percent of the salt in lake waters had been derived from sediments via upward salt migration during the previous 25 years, whereas external inflows contributed only 0.1

percent during the same period (Lerman and Jones 1973).

Conversely, when lake-water salt concentrations are higher than those in sediment interstitial waters – occurring when surface elevations are low – salt is removed from lake waters and transported to sediments via downward salt migration across a reversed concentration

gradient. The true extent of this process is unknown, but it may be negligible given that salt is far more abundant in sediments than in overlaying lake waters (Lerman and Jones 1973). Indeed, the “only effective means” of salt removal occurs during dry periods when lake levels are very low (Figure 9). Then, dried salt deposits on the exposed portions of lakebed and across the upland playa are swept up by strong winds and transported out of the lake basin (Van Denburgh 1975). When the exposed areas are flooded during high lake levels, a portion of the salt that has not been lost to wind is redissolved and restored to lake waters (Phillips and Van Denburgh 1971).

Lake Biology (Excluding Waterfowl and Shorebirds)

Lake Abert is devoid of fish and amphibians. In fact, few species are able to survive in the lake’s caustic, saline waters. For those species that inhabit the lake, their abundance and survivability depend greatly, if not entirely, on lake-water salinity. Among invertebrates, for example, brine shrimp (*Artemia* sp., Figures 10 and 11) and alkali flies (*Ephydra hians*, Figure 12) predominate and can be hugely productive when salinities range between about 25 to 100 g/liter. When salinities either fall below or exceed this range, populations of both organisms decline significantly (Herbst 1994).

During the period roughly 1983 to 1986, as salinities fell to around 20 g/liter due to high-water conditions, alkali flies nearly disappeared while species able to tolerate fresher waters prevailed (Herbst 1994). These species included oligochaetes (aquatic earthworms), amphipods (*Hyallela azteca*), damselflies (*Enallagma clausum*), backswimmers (*Notonecta spinosa*), water boatmen (*Corisella decolor*), predaceous diving beetles (*Hydroporus striatellus*, *Hygrotus masculinus*), water scavenger beetles (*Berosus fraternus*), “long-legged” flies (*Hydrophorus plumbeus*), soldier flies (*Odontomyia* sp., *Stratiomys* sp., *Nemotelus* sp.), and horseflies (*Chrysops* sp.).

Relatively high-water conditions of the mid-1980s were followed by drought years that greatly reduced lake volume and increased salinities. By 1992,



Figure 9. From left to right, Keith Kreuz (Oregon Desert Brine Shrimp Company) and Trent Seager (Oregon State University) collect water and biological samples at Lake Abert, April 24, 2010. Lake surface elevation then was about 4,248.3 feet (amsl). Photo by Ron Larson.



Figure 10. Brine shrimp from Lake Abert (*Artemia* sp.), September 5, 2010. Photo by Ron Larson.



Figure 11. A surface scum of dying and decomposing brine shrimp stain the nearshore waters of Lake Abert, September 5, 2010. Tufa (CaCO_3) deposits encrust a shoreline rock. Photo by Ron Larson.

surface-elevation stood at 4,250 feet (amsl) or less, resulting in salinities as high as 180 g/liter. Herbst (1994) reported that the lake's benthic community had been "all but eliminated," with alkali fly larvae present only in small numbers. Within a year, however, wetter conditions returned and the lake's volume increased, lowering salinities to levels optimal for alkali flies and brine shrimp, both of which proliferated. Other species also reappeared in fair numbers, including *Hydrophorus plumbeus* ("long-legged" fly), *Chrysops* sp. (horsefly), *Odontomyia* sp. (predaceous diving beetle) and the amphipod, *Hyallela azteca*, albeit rare (Herbst 1994).

The invertebrates identified by Herbst (1994) represent nearly all that have been found in Lake Abert. Forester (1983) reported the occurrence of an ostracod, *Limnocythere sappaisensis*. And, in 1962 and 1965, organisms thought to be snipe flies (*Atherix* sp.) were collected by Dr. R.W. Castenholz, University of Oregon (unpublished field notes). Castenholz's collections also included rotifers (*Hexarthra* sp.) and cladocerans (*Daphnia similis*, *Moina hutchinsoni*), but no copepods (unpublished). Fairy shrimp (*Branchinecta gigas*, *B. mackini*) have also been observed (Keith Kreuz, pers. comm.)

The lake's botanical assemblage is similarly species-poor, but the organisms that exist can be highly productive when salinities are within an optimal range

for each species. Primary production originates largely in the benthic region where the predominant organism is the green alga *Ctenocladus circinnatus*. This species is most productive when salinities range between 25 and 75 g/liter, with production continuing to a salinity of about 100 g/liter but at a reduced rate. Production stops somewhere between 100 and 150 g/liter (Herbst 1994, Herbst and Castenholz 1994, Herbst and Bradley 2004).

Incorporated with benthic vegetation are diatoms (*Nitzschia frutulum*) and cyanobacteria, including *Oscillatoria* sp., *Anabaena* sp. and *Spirulina* sp. (Herbst 1994). Whether these are planktonic organisms that settled into the benthos, or are benthic in origin, is perhaps unknown. Castenholz (unpublished field notes) collected diatoms (*Anomoeoneis sphaerophora*, *Nitzschia* sp.), cyanobacteria (*Oscillatoria* sp., *Spirulina* sp., *Anacystis marina*) and green algae (*Chlorella* sp., *Ctenocladus circinnatus*, *Cladophora* sp., *Characium* sp.), noting that *Characium* sp. was attached to cladocerans and rotifers (i.e., epizoic).

Relatively thick deposits of calcium carbonate (CaCO_3), or tufa, encrust exposed rocks along the lake's shoreline (Figure 13). These deposits result from the precipitation of CaCO_3 in highly alkaline, saline lakes that are supersaturated with CaCO_3 (Kalf 2002). Precipitation may be biologically induced whereby algal primary production is sufficiently high to deplete carbon dioxide (CO_2) in lake waters. As CO_2 diminishes, pH levels rise to 10 or higher, thus reducing carbonate (CO_3) solubility and causing CaCO_3 to precipitate. But algae-related CaCO_3 precipitation may be a minor process: In Lake Abert, CaCO_3 is precipitated mostly because of its supersaturated condition.

Waterfowl and Shorebird Populations

Water birds make extensive use of Lake Abert for foraging, molting, and pre- and post-breeding migration. Water-bird census data have been collected at the lake for several decades by various agencies and volunteers (Table 4). Total numbers of bird-use days (i.e., the number of birds present per day times number of days) can exceed three million, with peak daily counts of over 50,000 birds reported



Figure 12. Alkali flies (*Ephydra hians*) feeding in shallow waters at Lake Abert, August 28, 2010. Photo by Ron Larson.



Figure 13. Tufa (CaCO_3) deposits on shoreline rocks at Lake Abert, August 2009. Photo by Ron Larson.

Table 4. Some Reported Maximum Numbers of Waterbirds Observed at Lake Abert.

Species	No. of birds ¹	Date	Source
American avocet (<i>Recurvirostra americana</i>)	15,345	Aug 97	Warnock et al. 1998
western sandpiper (<i>Calidris mauri</i>)	15,000 ²	May 89	Kristensen et al. 1991
Wilson's phalarope (<i>Phalaropus tricolor</i>)	60,000-70,000	Jul 82	Jehl 1988
red-necked phalarope (<i>Phalaropus lobatus</i>)	43,450	Aug 95	Sullivan 1996
eared grebe (<i>Podiceps nigricollis</i>)	30,000	Apr 94	Tweit et al. 1994
ring-billed gull (<i>Larus delawarensis</i>)	20,000	Fall 96	Sullivan 1996
California gull (<i>Larus californicus</i>)	8,000	NA ³	Marshall et al. 2006

¹ Single-day counts

² Count consists "mostly" of western sandpipers

³ Data not available

occasionally. These densities demonstrate Lake Abert's immense importance to migrant Great Basin shorebirds, an importance that is probably surpassed only by the Great Salt Lake in Utah (Boula 1985; Warnock et al. 1998).

Wilson's phalaropes (*Phalaropus tricolor*) can reach seasonal densities that rank among the highest ever reported in the United States. Red-necked phalaropes (*P. lobatus*) are also extremely abundant since the lake provides them an important migratory stopover. These small birds probe for prey in shallow waters and peck at swimming prey in open waters. Phalaropes characteristically display a swirling, swimming behavior that brings plankton closer to the surface where the birds can reach it.

American avocets (*Recurvirostra americana*, Figure 14) are seasonally numerous and can be seen in groups of several thousand in foot-deep water using their long, up-curved bills to probe for prey or to contact prey by sweeping their bills through the water like a scythe. Other abundant water birds include (1) western and least sandpipers (*Calidris mauri* and *C. minutilla*), which are small shorebirds that rapidly probe in the mud along the shore and in inch-deep water (Figure 15); (2) eared grebes (*Podiceps nigricollis*) that feed in open water by pecking prey from the surface; (3) California and ring-billed gulls (*Larus californicus* and *L. delawarensis*) that feed along the shore and in open water by pecking at prey; and (4) northern shovelers (*Anas clypeata*)

that use their spoon-shaped bill to strain zooplankton from the water.

Water birds are greatly attracted to Lake Abert's seasonal abundance of invertebrate prey, primarily alkali flies and brine shrimp. These organisms provide food that is readily accessible and energy-rich during migration when food is especially important (Boula 1985). Unlike freshwater lakes, where the trophic structure is complex, and where fish are often the major predators, hypersaline lakes have a relatively simple food web: benthic algae as major primary producers, alkali flies and brine shrimp as dominant primary consumers, and water birds as principal predators (Boula 1985).

Most of Lake Abert's water birds are migratory; some will fly several thousand miles or more each year between breeding and wintering areas. Wilson's phalarope, for example, breeds in northwest wetlands, but overwinters in high-elevation Andean lakes. The least and western sandpipers nest in the subarctic of Alaska and Canada and overwinter along the Pacific Coast extending from the United States to South America. Gulls and other species may migrate only short distances between breeding and wintering grounds.

Few water birds nest at Lake Abert. These include the snowy plover (*Charadrius alexandrinus*), a small, light-colored shorebird adapted to foraging and nesting in the alkali-encrusted playa habitat at the lake margins. There, protective cover is very limited and mid-

summer air temperatures are typically high. The snowy plover has good vision and runs quickly over the dry, salty crust to grasp insects, including alkali flies (Stern et al. 1990). The snowy plover population at Lake Abert is not large, with peak numbers of only 300. But they comprise about one-third of the total interior population in Oregon (Marshall et al. 2006). Along the Oregon Coast, where the snowy plover also nests, the bird is listed as federally threatened under the Endangered Species Act because of habitat disturbance and other factors. Interior populations are larger, but periodic drought and anthropogenic water-diversions can decrease food and habitat availability. Other water birds, such as the American avocet, nest in freshwater marshes at nearby Summer Lake but feed at Lake Abert. This use of diverse aquatic habitats nearby to fulfill various biological needs contributes largely to Lake Abert's water-bird diversity and the birds' resiliency.

As discussed earlier, optimal lake-water salinity conditions are vital to the lake's considerable importance as a critical migratory stopover and "refueling station" for water birds. Few other lakes in the region serve this purpose – indeed none to the extent that characterizes Lake Abert. Although the lake's salinity is regulated mostly by drought and other natural phenomena, human activities such as upstream water diversions can also have an impact. It is essential, therefore, that these activities be controlled or partly



Figure 14. American avocets at Lake Abert, August 28, 2009. Photo by Ron Larson.

eliminated. Droughts and water diversions reduce lake levels, resulting in suboptimal salinity conditions that adversely affect the birds' food sources, primarily alkali flies and shrimp. Consequently, bird populations will suffer higher mortalities and reduced productivity.

Commerical Fishing in a Fishless Lake

Keith Kreuz, owner and operator of the Oregon Desert Brine Shrimp Company, has been harvesting brine shrimp at Lake Abert every year since 1979. Kreuz, who holds a M.S. degree in fisheries from Oregon State University, conducts his harvest from a motorized raft powered by an eight-horsepower outboard motor and equipped with two plankton nets that are towed (Figure 16). He "trawls" for about two hours, during which time he collects an average of 400 to 500 pounds of brine shrimp on good days. Once collected, the shrimp are transported to Kreuz's packaging plant in the nearby town of Valley Falls where Kreuz's wife Lynn and summer-student helpers process, package, and freeze the shrimp for shipment (Figure 17). Kreuz's commercial "fishing" season typically lasts for three to four months, beginning in May if the shrimp have attained a size of 8 to 10 mm. Fishing ends sometime in August, often in early August if the population crashes that soon.

Generally, if lake-water salinity is within the optimal range for brine shrimp, the annual harvest can exceed 50,000 pounds. When salinities are suboptimal, however, the annual harvest can fall to 4,000 pounds or less. But whatever amount is harvested, preseason predictions about what the lake will yield are usually unreliable since shrimp abundance can vary by as much as 90 percent from year to year.

The shrimp are sold to a wide variety of customers, including businesses that produce, raise, and market tropical fish, companies that manufacture flake food for tropical fish, and U.S. federal and state fish hatcheries. Large quantities are now being sold to foreign aquaculture industries that produce larger shrimp. Until recently, these industries depended mostly on China for brine shrimp. But disease problems have crippled China's brine-shrimp operations, forcing shrimp



Figure 15. Western sandpipers at Lake Abert, August 28, 2009. Photo by Ron Larson.



Figure 16. Keith Kreuz, Oregon Desert Brine Shrimp Company, trawls for brine shrimp on Lake Abert, summer 2007 or 2008. Photo by Lynn Kreuz.

producers to seek brine shrimp from disease-free sources such as Lake Abert.

Finally, concerns that the harvests pose a threat to the lake's ecology, or reduce brine shrimp to a level where the population cannot recover, have been dismissed by scientists who study the lake (Wray 1993). In order to harvest the lake's shrimp, Kreuz is required to have a Commercial Bait License, a Limited Entry Permit, and a Bait Dealers License that are issued by the Oregon Department of Fish and Wildlife (ODFW). He is also required to submit fish tickets to ODFW weekly to document his catch for the week. At the end of each month he pays ODFW 2.5 cents per pound of shrimp caught. Additionally, since the lake is mostly on federal land, Kreuz is required to have a permit from the Bureau of Land Management to access the lake.

Saving Lake Abert

Aside from Keith Kreuz and a handful of scientists, few people visit Lake Abert due to the fact that recreational opportunities typical of freshwater lakes are lacking. As mentioned, the lake is fishless, and the lake's saline, alkaline waters are too harsh for swimming. The lake is too shallow for boating, particularly during low-water years when depths average less than ten feet. The land around the lake is barren and, according to Wray (1993), teems with rattlesnakes.

During the 1960s, efforts were made by the Oregon State Game Commission and the Bureau of Land Management to enhance the lake's recreation potential by introducing fish. Experiments were first conducted by placing live-boxes containing salt-acclimated chinook and coho salmon into the lake. The fish quickly died. A subsequent laboratory experiment involved the introduction of five fish species from California's Salton Sea into various mixed proportions of Salton Sea water and water from Lake Abert. Only one of the species was able to survive for 23 hours in a water mixture consisting of 50 percent Salton Sea water and 50 percent water from Abert. The desert pupfish was most tolerant of Abert water, surviving 18 hours in a mixture consisting of 25 percent Salton Sea water and 75 percent Abert. When introduced to 100 percent Abert water, none of the



Figure 17. Lynn Kreuz, Oregon Desert Brine Shrimp Company, fills product containers with brine shrimp prior to shipment, summer 2007 or 2008. Photo by Keith Kreuz.

five species survived, thus demonstrating why the lake is fishless and will remain so (Mastin 1972).

Unfortunately, because the lake is unsuitable for recreation and is located in a remote, desolate area of Oregon's high desert, the public generally regards the lake as a body of degraded, briny, foul-smelling water unfit for most aquatic life. In fact, few people know where the lake is located, even though it is one of Oregon's largest lakes and is adjacent to a major highway.

Historically, government and corporate ambitions for the Lake Abert basin have seemingly ignored the delicate ecological balance between salinity and the lake's aquatic life. In 1988, the U.S. Geological Survey set out to detonate four tons of high explosives on the bottom of the lake to study seismic properties of the region's lithosphere. This plan was canceled after the USGS was warned that the blast would damage Native American burial grounds and nesting areas for Oregon's threatened snowy plover (Rollins 1988). Other failed schemes included a large-scale Canadian mining operation to extract salt from the lake bottom; a hydroelectric project to pump lake water 2,400 vertical feet to the top

of Abert Rim before releasing it back to the lake for power generation; and a dam on the upper reaches of the Chewaucan River, the lake's principal source of water.

In 1991, the State of Oregon and the federal government authorized a private developer to impound the Chewaucan River with a crude, earth-filled dam, 23 feet tall (refer back to Figures 8 and 9). Freshwater that should be flowing into Lake Abert to maintain optimal salinity levels is now being withdrawn from the reservoir – covering anywhere from 650 to 1,400 acres – to irrigate marginal agricultural land. This, combined with a natural water shortage in the region, possibly related to climate change, imperils the lake's fragile ecology and upstream agricultural diversions. To maintain optimal salinities of between 30 and 80 g/liter, lake surface elevations should range, ideally, between 4,252 feet to 4,258 feet, amsl (Keister 1992).

A renewal permit to continue the dam's operation is currently under review by the Oregon Water Resources Department. But removing the dam entirely would have a more lasting and purposeful effect, freeing the river and saving one of the world's great saline lakes.

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