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Discussions of salinity in Arizona generally begin with the Colorado River, the largest, most managed and controlled of western rivers. (Photo: George Andrejko, Arizona Game & Fish Dept.)

Does Salinity Pose Problems to Arizona Water Users?

by Joe Gelt

Someone who is described as the "salt of the earth" is considered to be a goodly person. Salt with earth in this case connotes an unaffected beneficence. Salt with water however has less favorable implications in certain parts of the United States, especially in Arizona and the West. Salt combined with water produces saline water and poses water quality problems in the region.

No geographic area is immune to the adverse effects of salinity in its soils and water. Salinity is a problem of special concern however in arid and semiarid regions, including the U.S. Southwest. Often characterized by hot, dry weather, these areas are likely to experience limited rainfall and have a high evaporation rate. As a result, less water is available to dilute salts in water supplies, and less rushing water flows to flush waterways. Geological conditions may further contribute to the occurrence of salts.

Saline water occurs throughout Arizona, in various locations. Its presence depends upon a number of variables, some related to natural processes and others to human activities. For example, in the northern part of the state groundwater tends to be naturally saline due to geologic factors. This situation is contrasted with the low saline concentrations of Tucson's groundwater. Thought to be caused by both natural conditions and human activities, the salinity in the City of Chandler's water supply is high enough to require desalinization.

That a major state waterway is called the Salt River indicates that at least some of Arizona's surface water is saline. And not to be overlooked when salinity is the topic, the Colorado River, along with establishing the western boundary of Arizona, provides a case study of the hydrology, geology, and politics of salt.

Salinity includes the following major constituents: calcium, magnesium, sodium, bicarbonate, chloride, and sulfate. Saline conditions – and their detrimental effects – vary depending upon which, and in what concentrations these constituents occur. General salinity concentration is usually measured as total dissolved solids (TDS), a formula combining all dissolved mineral salts. TDS is expressed as either parts per million (ppm) or milligrams per liter (mg/l). The measurements are basically identical. As an example and a point of reference, the TDS of sea water is 35,000 ppm or mg/l.

The Problems with Salt

By evaluating the possible adverse effects of saline water use, its priority as a water quality issue is established. In other words, if consequences are severe and undesirable, there is a greater cause for concern and a need to take action. What then are the possible consequences of using saline water?

Salinity in drinking water is not generally perceived as posing a health risk for a wide range of concentrations. In fact, EPA has not established primary drinking water standards for salinity. The agency however does recommend that water with a salinity level of over 500 mg/l not be used for drinking, if other sources are available. Taste is the primary concern here. Arizona has not set salinity levels for either ground or surface waters, except in a special case on the Colorado River, to be discussed later.

Excessive salinity can be a cause for worry in agricultural irrigation for several reasons. A prime concern is that it impedes crop growth. For example, severe salinity adversely affects water uptake by plants, thereby limiting crop yields. Also, sodium, a component of some salts, impairs soil texture and permeability. Higher production costs result, with a need for more intensive management. Soil conditions and type of crops grown are variables determining the extent of agricultural loss.

Irrigation with saline water poses another type of salinity problem, with consequences beyond agriculture; i.e., the buildup of salt in the soil. About half of the irrigation water applied to crops is lost to evapotranspiration. What is left behind in the soil is an elevated concentration of salts.

If these salts are allowed to build up at the root zone, soil toxicity could result, a condition that has adversely affected the agriculture of various civilizations, possibly even the Hohokam. To avoid this situation the mineral buildup is often leached or flushed to drain into a river system, with some flow possibly reaching the groundwater table. One consequence of the above is increased water use, which undermines efforts to conserve water. Another possible result is saline contamination of groundwater and surface water, thus limiting the usefulness of such water supplies.

Industrial losses are to be expected with water above 500 mg/l. The type and extent of concerns relate to the kind of industry and whether its processes require relatively pure water. Additional expenses result if blending and pretreatment are needed to soften water and protect against corrosion, a likely procedure if an industry's water source is in fact saline.

Municipal use of saline water raises additional concerns. With increased corroding and scaling of metal pipes and fittings, water heaters and appliances will need replacing more often. Fabric life will also be reduced. Increased cost will be incurred as bottled water and water softeners are purchased.

The Salty Colorado

Discussions of salinity in Arizona generally begin with the Colorado River, the largest and most managed and controlled of western rivers. Of all U.S. river systems, the Colorado presents the most extensive and complex salinity problems. During its long course and flow, this river system accumulates, distributes, and redistributes salts over a vast geographic area. From its source to its mouth, the Colorado River picks up about 9 million tons of salt.

To all who use or have claims to the waters of this river – and this includes interests at the state, regional, tribal, and international levels – its salinity and its effects are matters of great concern. With its waters valued and shared by a number of interests for various uses, the Colorado River represents the salinity problem in the West writ large.

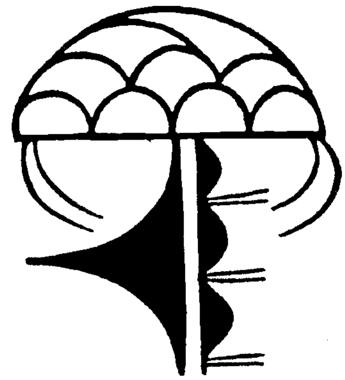
Much of the salinity of the Colorado River is the result of natural conditions. Ancient seas once covered much of the 244,000-square-mile area now drained by the river. What remains are vast areas of marine shales or old sea floors, where salt accumulations are an expected phenomenon, a natural occurrence. Here are rich salt deposits to wash into the Colorado River.

Human activities also contribute to the river's salinity. As would be expected, the effects of such activities have intensified with the growth and development of the region. For example, the salinity level of the Colorado River at its source high in the Rocky Mountains is about 50 mg/l. In the late nineteenth century, before the river was vigorously managed, developed, and exploited it flowed into Mexico with a salt content of about 400 mg/l. Now, almost a century later, the Colorado River reaches Mexico with about 800 mg/l. The difference in recorded salt levels of waters entering Mexico between the two dates is one measure of human complicity in the salinity of the Colorado River.

Irrigated agriculture is one type of human activity contributing to the river's salinity. The United States Department of Agriculture estimates that about 1.7 million acres of farmland are irrigated within the Colorado Basin. It is further estimated that this situation accounts for about 37 percent of the river's salt load.

Further contributing to the salinity of the Colorado River is the evaporation from reservoirs and conveyance systems that store and transport its waters. Because of these structures evaporative surfaces are greatly expanded. The resulting increased evaporation means a higher concentration of salt in the remaining waters. According to Bureau of Reclamation studies, this situation accounts for about 12 percent of Colorado River salinity.

Colorado River diversions play a role in increasing the salinity of its flow. Water from the Colorado River is exported to eastern Colorado, Utah's Great Basin, New Mexico's Rio Grande Valley, Southern California and, of course, central Arizona via the Central Arizona Project. Close to the river's headwaters, the upper basin states, which pump water that is relatively pure, are increasingly using their shares of Colorado River waters. The result is a higher salt con-



San Ildefonso pottery design of clouds with rain

centration, especially in downstream areas. According to Bureau of Reclamation figures the approximately 5 million acre-feet diverted annually contributes about three percent to Colorado River salinity.

Another variable that effects salt concentration is the quantity of river flow. High flows dilute the waters and flush and fill reservoirs. This condition was evident between 1982 and 1987, a period of relatively high precipitation and therefore less salt concentrations. At that time salinity was about 600 mg/l at Imperial Dam. Since then however salinity has been increasing, with levels now at 800 mg/l.

The general trend is for the Colorado River to gain salinity as it flows south. Agricultural activities in the upper basin contribute salts to the river, while reservoir evaporation and major diversions deplete river water in the lower basin. The net result is more salt in less water in the lower reaches of the river.

United States, Mexico, and Salt

As a result of the above factors, an oft diverted, much used Colorado River finally enters Mexico, a remnant or leftover flow from myriad U.S. uses. Its condition as it flows into Mexico has been the cause of international dispute.

Salinity was not an issue in 1922 when the Colorado River Compact divided the waters of the Colorado among the upper and lower basin states. Quantity was the concern, not quality. Nor was salinity at issue in the 1944 U.S.-Mexican Colorado River treaty that guaranteed 1.5 million acre-feet of water per year to the southern country.

Salinity however was indeed the issue in the 1960s when the quality of water flowing into Mexico significantly dropped. How could it not be when, because of Bureau of Reclamation projects in Arizona, the salinity of water entering Mexico leaped from 800 mg/l in 1960 to more than 1500 mg/l in 1962? This devastated a prosperous agricultural region just south of the border. Mexico vigorously objected.

An international dispute resulted. Viewing itself as an aggrieved party, Mexico claimed purer, less saline water was its due per the 1944 treaty. The United States responded that the treaty merely ensured the delivery of a set quantity of water, without stipulating the quality of that water. The US therefore claimed that the delivery of saline waters was indeed fulfilling the terms of the treaty.

The dispute lingered until 1974 when an accord was reached between the two countries. Basic to the settlement was an agreement by the United States to manage and control the salinity level of the Colorado River flowing into Mexico. Such waters were now to have an annual average salinity of no more than 115 mg/l, plus or minus 30 mg/l, over the recorded average salinity at Imperial Dam, the last U.S. dam before the border.

Arizona Gets Involved in Salinity

Thus established as an international concern, salinity was also emerging as an issue within the United States at this time. Seeking to enforce the recently passed Clean Water Act, the newly formed Environmental Protection Agency put the seven Colorado basin states on notice in 1972 to set legal salinity standards. The states resisted arguing that a regional or basin-wide approach to the salinity problem is superior to each state working out its own standards. To better advocate this position, which the EPA eventually accepted, the basin states organized the Colorado River Basin Salinity Control Forum.

Now working with the Forum, the EPA insisted that standards be set for salt in the lower river at 1972 levels. Such standards were eventually worked out, with three stations established: 723 mg/l below Hoover Dam, 747 mg/l below Parker Dam, and 879 mg/l at Imperial Dam. That the standards are increasingly saline southward reflects the nature of the Colorado River and its use. It was estimated that to meet the set standards approximately 1.3 million tons of salt would need to be kept from the river annually.

The salinity of the Colorado River was obviously an emerging issue. In 1974 it was taken up by the U.S. Congress when it passed the Colorado River Basin Salinity Control Act. The act authorized a program for enhancing and protecting the quality of Colorado River water for use in the United States and Mexico. Title I of the act addressed the U.S. obligation to Mexico to control the salinity of Colorado River waters entering that country. Funds were authorized to construct a desalinization plant in Yuma, Arizona.

Title II of the act set up the Colorado River Basin Salinity Control Program. Individual salinity control projects were to be developed to ensure that the standards agreed upon by EPA and the states would in fact be met. Title II projects are mainly located in the upper basin states, with none established within Arizona. This is partly because Arizona's main tributary into the Colorado River, the Gila River, joins the river south of Imperial Dam. Title II only applies north of Imperial Dam.

The Colorado River Basin Salinity Control Forum is involved in working out the Title II program. Composed of up to three governor-appointed representatives from each of the seven Colorado River Basin States, the Forum is to ensure interstate cooperation on salinity issues. The Forum's responsibilities include a triennial review of the 1972-established Colorado River salinity standards. The Forum has regularly recommended the continuation of these standards.

Controversy and dispute have at times plagued the implementation of the Title II program. Initially relying on a strategy of structural modifications and changes, Title II projects have recently shifted to encouraging on-farm irrigation efficiencies to control salinity. Some officials fear that decreased funding will eventually undermine Title II operations.

Basic to Arizona's involvement in Colorado River affairs is the river's importance as a source of water to the state. Arizona is entitled to 2.8 million acre-feet of Colorado River water, which is diverted at various locations along its course. Backed up at Parker Dam the Colorado River forms Lake Havasu, the diversion point for the Central Arizona Project.

Before flowing to the next major Arizona diversion point at Imperial Dam, the Colorado River provides water to Bullhead City, Lake Havasu City, Parker, and the state's Colorado River Indian reservations, as well as other minor diversion points. At Imperial Dam, about one million acre-feet is diverted for Arizona's use at Yuma and to serve agricultural districts.

CAP Waters and Salinity

A manmade, force-fed tributary of the Colorado River, the Central Arizona Project canal is spreading the waters, with Colorado River water now flowing to the central, highly populated region of the state. Initially committed to agricultural uses, CAP water will increasingly serve urban needs. Various questions are thus raised: Will this greater and more extensive use of Colorado River waters pose any salinity concerns to areas of the state served by the CAP? And, if so, what would be the nature of those concerns, and who would be affected?

Officials point out that the salinity level of the Colorado River at the CAP diversion point is not extreme. CAP waters are diverted at Lake Havasu, before the occurrence of heavy irrigation return flows, and are expected to be mostly within the low 600 mg/l range. Even if the salinity level should rise to the mid-800 mg/l range, the highest likely future rate expected by some officials, the water would still be acceptable for most designated uses. Further, some officials are confident that the Title II salinity control program operating in the northern reaches of the Colorado River will generally maintain a suitable salt level.

Potential exists however for the salinity of CAP water to have some effect on agriculture. University of California Cooperative Extension Guidelines indicate that water of 500 mg/l salinity is safe, but as salinity rises to between 500-1950 mg/l the potential for agricultural problems increases. CAP salinity is expected to vary, a range of between 537-730 not unlikely. Some concern therefore may be justified. In many situations, however, especially in Pinal and Maricopa counties, CAP water is an improvement over supplies in use prior to CAP coming on-line.

Studies were conducted to determine the costs of CAP salinity to various urban entities—residential, commercial, and industrial. Diverse opinions resulted, from no effects at all to expenses of varied amounts. Most studies however show no major impacts, with many variables at work determining what in fact will be the costs. For example, industries will be affected depending upon the type of work they are engaged in and its required processes.

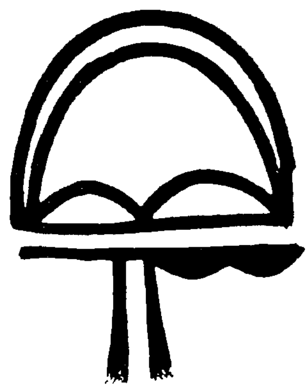
The acceptance of CAP water by residential and commercial entities depends to some extent on salinity levels of their pre-CAP water sources—or what kind of water they were use to. In this situation, as in many others, Phoenix and Tucson, the states two major urban areas, provide a contrast.

Prior to the arrival and use of CAP water, Phoenix mainly relied on water from the Salt River, a source with a salinity level of between 500 to 700 mg/l. CAP water therefore did not represent a major salinity change. In fact, CAP waters have less salts than Salt River water during low-flow years. Plans are to recharge CAP water even when it is more saline than the underlying groundwater. Whatever groundwater quality changes may occur are not expected to be severe. CAP recharge may actually improve the groundwater in some situations.

Until CAP comes on-line, Tucson will have been using groundwater with a salinity level of about 300 mg/l. CAP waters are nearly twice the salinity of Tucson's native groundwater supply. This before-and-after comparison sparked concern about CAP salinity among some citizen groups. Water officials however tended to argue that whatever inconveniences result from the slight decrease in water quality is more than compensated for by having access to this new water source.

To desalinate or not was a question raised when Tucson's CAP water treatment plant was discussed. It was decided however that the additional costs involved in desalinization were not justified in terms of any perceived benefits.

Municipal concern about CAP salinity tends to be mitigated by the fact that its effects occur very gradually. Because of this some officials argue that the additional cost of CAP salinity to residential water users may go more-or-less unnoticed. Admittedly, because of scaling or corrosion, water heaters may need to be replaced more frequently. No cause-and-effect relationship may be perceived however between the water heater's deterioration and CAP salinity.



San Ildefonso pottery design of clouds, rain, and the arch of a rainbow

And besides, even if it were understood as due to salinity, the occasional expense of replacing water heaters would be more readily accepted than an increased monthly water bill for the cost of desalinating. Water bills might actually double with desalinization. In sum, desalinating water of 600 to 700 mg/l, which is the range of CAP water, is not considered a likely strategy.

Salinity is an issue in Arizona extending beyond the flow and use of Colorado River water. Concerns about salinity are also linked to reclaimed water use, an application of increasing importance.

Reclaimed Water and Salinity

Water reclaimed is water recycled, and the process generally results in increased salinity. Wastewater is treated, reused as reclaimed water, then returned to the treatment plant as wastewater to be treated once again for reuse, with salt increasing with each recycling. Estimates are that one cycle of municipal use increases the salt content of water by 200 to 400 mg\l. Sanitary discharges and water softeners contribute to the salinity of reclaimed water.

Salts are not removed during wastewater treatment. The existing wastewater treatment process is designed to remove bacterial and organic waste matters. Salt removal involves using membrane filtration techniques; e.g, reverse osmosis, nanofiltration or distillation. These are expensive procedures, and unlikely to be implemented unless wastewater is to be treated for potable use.

CAP waters will contribute additional salinity to the process. When CAP water is reclaimed, Colorado River salts will figure into the equation or cycle. The net result is an increased salinity of reclaimed water.

The salt composition of reclaimed water is likely to differ from other water sources with saline concentrations. For example, reclaimed water is likely to contain more boron, a common ingredient in household detergents. Small concentrations of boron are essential for plant growth but with slight increases beyond a basic amount, boron is toxic to plants. Also, reclaimed water is likely to be high in sodium, especially in areas where water softeners are commonly in use. High sodium concentrations in irrigation water may decrease soil permeability and reduce soil aeration.

The Arizona Department of Environmental Quality considered setting salinity standards for reclaimed water. If regulations were to be set, some officials argue they should be based on the degree of salinization of a reclaimed water source, the higher the salinity level the more restrictive its use. The effectiveness of establishing such a criterion is questioned, however, because many site-specific variables may affect what salinity concentrations are tolerated at a certain location. Such variables include the type of crops to be irrigated, the local climate, the soil type, and drainage conditions.

Other officials suggest an alternate method of regulating reclaimed water that would control the amount applied in irrigation. By prescribing how much reclaimed water is to be used for irrigation, suitable leaching could be ensured to stabilize soil salinity at a fairly constant value.

In opposition to the above options, some officials argue that regulations of salinity should not be confined to any one particular water source, such as reclaimed water. Instead, the larger hydrological context needs to be examined, with all the water sources of a particular basin or area reviewed to determine how each contributes to existing salinity problems or concerns.

For example, an effort to control the salinity within the Phoenix area would include an evaluation of the Salt and Verde river systems, CAP water, reclaimed water, and groundwater and how the various water sources are mixed and used by cities within Maricopa County. Only then it is argued can effective salinity regulations be devised that recognize the many variables involved.

Salinity levels in reclaimed water however may not now justify the need for such regulations. A review of treatment plants in the Tucson and Phoenix areas found acceptable concentrations of salts for all existing uses and conditions. In fact, salinity averages of the reclaimed water compared favorably with levels occurring in some surface water and groundwater sources. As a result, no actions are anticipated at this time. The overall effect of salt buildup from repeated recycling however may eventually require that some actions be taken.

Salinity and Groundwater

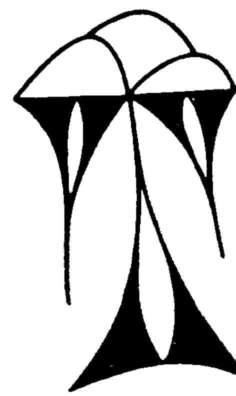
Occurring gradually, the effects of salinization are most evident by their impacts on various water-consuming entities – households, businesses, agricultural operations, and industries. Along with these effects however is another, not as readily apparent perhaps, but portending far-reaching consequences – the salinization of the state's groundwater resources.

Mandated by the 1980 Groundwater Management Act, Arizona is committed to preserving its groundwater resources. Basic to this commitment is the recognition that groundwater is a valuable future resource, to be protected and preserved. Thus, threats of groundwater contamination need to be carefully evaluated, since salinity would limit the usefulness of this important resource.

It is generally recognized that long-term use of an aquifer may result in a buildup of its salinity. For example, Phoenix's groundwater has increased in salinity over the years due to natural occurring salts and partly because of agricultural use and return flows. Salinity levels however are not considered excessive.

Other types of situations however may have a more severe effect. For example, highly saline groundwater may result when an aquifer is overly mined. As the upper levels of groundwater are drawn off, the watertable drops. Water must then be pumped from progressively lower in the aquifer. Water at this level tends to be more saline. The net effect is a depleted, saline aquifer.

Also, irrigation, whether agricultural or urban, has the potential to increase the salinity of groundwater. Some hydrologists believe that the full effect of this development may not yet be evident. They claim that salts from irrigation are being leached from soils and are percolating through the vadose zone. Meanwhile, because of regular and excessive pumping, the watertable is rapidly dropping and is therefore beyond the reach of saline



San Ildefonso pottery design of clouds with rain

recharge. In the future, because of Arizona's Groundwater Management Act, less groundwater is expected to be pumped. With the watertable thus stabilized the saline water will reach and mix with it.

This is perceived as a long-term process. For example, the saline waters may be moving through the vadose zone at ten feet per year, with the groundwater at a depth of 500 feet. The other variable to consider is the rate at which the watertable is dropping. Also, the saline waters will at first contaminate the surface of the aquifer, before reaching the lower depths and the well intake. The increased salinity of the groundwater therefore may not be apparent for a number of decades.

Concern has been expressed that public policy may be contributing to groundwater salinity. In a University of Arizona doctoral dissertation, Craig Tinney argues that certain components of Arizona's water conservation program can exacerbate the potential for salt concentration within groundwater.

Arizona's strategy to conserve groundwater includes importing CAP water and the reuse of wastewater. Both are water resources of various and sometimes elevated salinity. Tinney is concerned that, because of salt concentrations, these water supply alternatives pose long-term water quality problems.

When used extensively for irrigation, reclaimed water is of special concern. Tinney figures that in some situations, reclaimed water concentrations of 500 mg/l may increase to as much as 2500 mg/l when it reaches groundwater depth because of crop production.

Reclaimed water is extensively applied in urban areas, in parks, playgrounds, artificial lakes, cemeteries, golf courses, and to serve various landscaping purposes. Often reclaimed water is applied over aquifers that conservation policies are designed to protect. The goals of conservation may be served, but Tinney believes groundwater quality may be compromised.

Tinney's research concentrates on the Tucson basin. His study concludes that, under conditions of limited dilution potential, extensive use of CAP water in municipal supplies, and 100 percent reuse of reclaimed water, the annual salinity pick-up rate in Tucson ranges from about 0.5 percent to nearly 2 percent. With a salinity pick-up rate of 2 percent, Tucson's immediate groundwater supplies could degrade from its present average salinity of 300 mg/l to 1000 mg/l in as little as 61 years. A salinity pick-up rate of 0.5 percent would cause the same level of salinity increase in about 240 years.

Some officials are more cautious when anticipating the long-term effects of saline water use. They may admit that the situation indeed sounds ominous when cumulative figures indicate the vast amount of salt settling on the state. (One million acre-feet of CAP water is to be imported annually into Arizona, with each acre-foot containing 2000 lbs of salt, and there is no CAP return flow.) Yet they argue that these vast amounts of salt seem less formidable, if the immense storage capacity of the vadose zone is considered, as well as the great quantities of groundwater available to dilute saline recharge.

Also it has been suggested that the anticipated saline groundwater crisis may be more distant in the future than some people are projecting. Rather than 60 years, the critical period may not occur for another 500 years, at which time the technology may be available to handle the problem. It is generally conceded however that the eventual, long-term effects of saline water use in Arizona is not readily known.

What to do With Saline Water?

What to do with saline water presents a problem. The solution that comes readily to mind, especially to the layperson, is desalinization. This is an unlikely option however when the expense is considered. Ongoing research has not yet been able to reduce the cost of desalinization below about $300 per acre-foot.

The cost overruns of the Yuma desalinization plant provide ample evidence of the expense of the process. Originally estimated to be constructed at a cost of $77 million, with an annual operating expense of $10 million, the plant now is expected to cost $261 million to construct and $20 million to operate annually. Much of the expense is due to the high energy demand of desalinization, with its resulting cost.

After the salts are taken out, the residual brine must be disposed of, another expensive proposition. Orange County in Southern California disposes of its brine into the ocean via a storm disposal system, an option obviously not available to Arizona. Here evaporation ponds will likely be needed.

Another solution to the problem of saline water is to research uses for it. For example, certain salt-tolerant plants, called halophytes, will grow in saline water, although such plants tend not to be as profitable to grow as more conventional crops, such as cotton. The jojoba bean is an example of a plant that grows with saline water and soils. Work is being done to find suitable halophytes to grow in Arizona.

Saline water has other types of uses also. For example, the Solar Energy Research Institute funded University of Arizona researchers Gray Wilson, Kevin Olson, Mary Wallace, and Mike Osborn to inventory Arizona's saline water resources. The purpose of the inventory was to identify saline water supplies capable of maintaining a microalgae production facility. The algal biomass can be converted to synthetic fuel.

Summary

Not an ubiquitous condition, salinity variously occurs in the waters of the state. It does not necessarily provoke controversy because salinity does not pose a public health concern. Salinity is hardly a water quality hot topic.

Yet salinity is a matter of some concern, with historical consequences of great magnitude, nothing less than the fall of civilizations. For example, the civilization of the Fertile Crescent of the Tigris-Euphrates Rivers, its fields gradually salting up for over 2000 years, eventually collapsed. Its agriculture became increasingly untenable because of salty soils.

More than portending the collapse of Arizona – possibly a much less likely event with the evolution of agricultural techniques and methods – the lesson to be learned from such examples as above is that salinity build up is a gradual, historical process. Arizona will become more aware of its effects with time and an increased use of saline water.

Another matter to consider is that Arizona, its settlement, development and its extensive agricultural production, are all relatively recent events in any long-term historical sense. (Indians were here farming long ago, but their activities were more localized and small-scale.) Now would be a suitable time, therefore, especially since the use of saline water sources is increasing, to evaluate the future effects of salinity and to devise effective policies for its control.

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