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The Salton Sea, a below-sea-level (-69 m) very large repository of agricultural drainage, in between Imperial and Coachella valleys, Imperial and Riverside counties, California.

IS THE IRRIGATION OF ARID LANDS A DOUBLE-EDGED SWORD?

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ABSTRACT. The irrigation of arid lands is typically a very productive enterprise; however, it also results in the production of large amounts of waste salts, primarily sodium and calcium cations. These salts need to be disposed of properly if the irrigation enterprise is to continue a normal course. Despite more than a century of experience, the disposal of waste salts arising from the irrigation of arid lands remains a decided challenge. The sustainable solution is the disposal of the waste salts by conveyance to the nearest ocean. Where the irrigation sites are located far from the ocean, this objective may prove to be very expensive. It is proposed here that societies must learn to pay for the adequate disposal of irrigation waste salt.

1. INTRODUCTION

Nature has time; humans do not. In the recognition of this truism lies the story we are about to tell. It took Nature millions of years to leach the salts out of the soil, into the rivers, en route to the oceans, their final destination. In contemporary times, humans have accelerated the leaching process by irrigating arid lands, ostensibly to augment the production of food and fiber. In this endeavor, which has taken place in earnest in the past century, humans have managed to mobilize more salts and to concentrate them where they did not exist before, all the while originating a difficult problem of disposal where the irrigated lands did not happen to lie in the immediate vicinity of the nearest ocean.

Two important issues may not have been fully recognized at the time: (1) arid lands naturally contain more salts than humid lands, and (2) if the newly available salts are allowed to sit around, eventually they are bound to reach the groundwater reservoirs, contaminating them with additional salinity for the foreseeable future. These propositions will now be explained.

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2. NATURE'S WAY

The oceans contain large quantities of salt ions, about 3.5% by weight, 35‰, or 35,000 ppm, mostly ions of sodium (Na^+) and chloride (Cl^-). This salt originated in the rock mantle, mobilized by leaching from the soil profile to the adjacent surface waters, and accumulated in the oceans throughout eons. The amount of leaching varies with local precipitation. Humid lands are subject to a lot of leaching; conversely, arid lands are subject to much less leaching. All soils originate in parent rocks, typically in the geographical vicinity, and they have a stock of *nutrients*, the chemical elements essential for life.

The quantity and quality of nutrients, and their related ions (cations and anions), are sourced in the originating parent rock. Four cations (from the group of **Alkali and alkaline earth metals**) readily stand out due to their wide availability and relative importance in life processes: sodium (Na^+), magnesium (Mg^+), potassium (K^+), and calcium (Ca^+). These common salt cations constitute about 11% of all the ions in the lithosphere (**Table 1**). Furthermore, their presence in the lithosphere is about evenly distributed, each varying in the range of 2% to 4%.

This is where the similarities end. Vegetative ecosystems are known to be *highly selective* in their use of these four common salt cations; they readily uptake magnesium and potassium, while largely wasting sodium and calcium. This selectivity manifests itself after leaching to the river waters, where the percentages of sodium and calcium together rise to about 24% of all salt ions, while magnesium and potassium jointly constitute only about 7% (**Table 3**). Therefore, sodium and calcium are delivered to the oceans in much greater quantities than magnesium and potassium.

Once in ocean waters, calcium (Ca^+) is taken out of solution by biological organisms for the building of shells and skeletons (Fig. 1) or by chemical precipitation, which leaves sodium to constitute the lion's share (84%) of the four common salt cations in ocean waters (**Table 4c**). Together with its ubiquitous partner the chloride (Cl^-) anion, sodium and chloride constitute about 86% of all the salt ions present in ocean water (**Table 3**). Therefore, throughout the passage of eons, the selectivity of the biosphere, with regard to the four common salt cations, has largely determined the present composition of the oceans' chemistry.

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Fig. 1 Seashells: Marine bivalves and gastropods from Shell Island, North Wales, Great Britain.

In summary, sodium and calcium are wasted by the terrestrial biosphere, eventually flowing into the oceans, where calcium is largely taken up by ocean biota. This leaves sodium, and its partner, chloride, as the only *true wastes* of Nature, left to accumulate in the world's oceans, thanks to gravitational forces, through geologic time. While the oceans act as the natural repository, it is clear that sodium and calcium first collect and start to accumulate in the land, where the vegetative ecosystems do not make use of them in the quantities in which they are present. If this were not the case, the oceans **would not be full** of sodium chloride at this time!

3. HYDROLOGY AND SOIL FERTILITY

Water has a very strong capacity to pick up solids. This is due to its small but appreciable *dipole moment*, a property of its molecular structure that enables it to dissolve *almost anything*. The dipole moment arises because oxygen is more negatively charged than hydrogen; thus, oxygen pulls in the shared electrons, increasing the electron density around itself (Fig. 2). This creates an electric dipole moment vector, with the partial negative charge on the oxygen atom. The dipole moment of water is $\mu = 1.85 \times 10^{-18}$ statcoulomb-centimeter (**Ponce, 2019**).

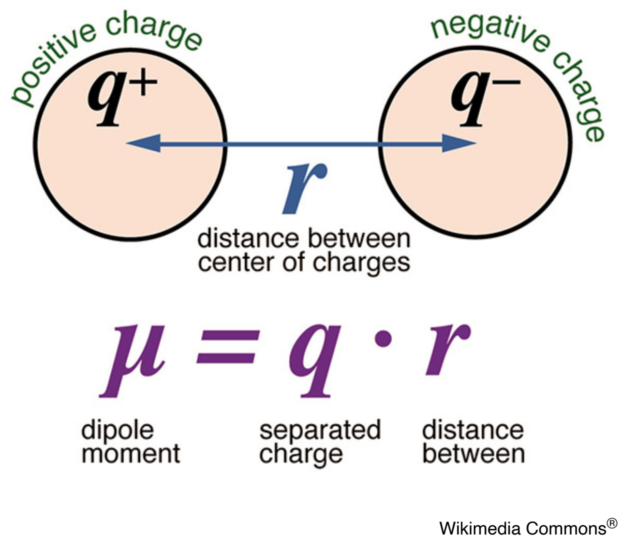

Fig. 2 The dipole moment.

All soils originate in the parent rock. They are produced by weathering and subsequent erosion, transported and deposited in the valleys, where the flowing surface water loses speed and ultimately deposits its load of sediments (boulders, gravel, sand, silt, and clay). The soil particles are loaded with nutrients, both internal, inside the soil particle's matrix, and external, on the surface.

At the time of soil formation, the quantity and quality of nutrients depended on the geological origin of the parent rock, whether igneous, sedimentary, or metamorphic. To an extent, it is also related to *the luck of the draw*: some soils contain specific quantities of certain nutrients; for instance, an example is the prominent presence of selenium in California's Central Valley, as well as in other regions of the Western United States (**Water Education Foundation, consulted on September 9, 2023**).

The water molecule's large dipole moment is responsible for setting in motion the continuous interaction of hydrologic science with soil science: The greater the amount of mean annual precipitation, the greater the amount of leaching of the underlying soils. Thus, subhumid to superhumid climates find their soils increasingly devoid of nutrients (**Ponce, 2023**). The dictum is: The greater the amount of mean annual precipitation, the lesser the amount of nutrients.

Conversely, the smaller the amount of mean annual precipitation, the lesser the possibility of leaching of the underlying soils. Therefore, semiarid to superarid climates find their soils filled with nutrients, many primeval, i.e., hardly, if ever used. The drier the climate, the greater the amount of nutrients likely to be stored in the soil profile. In this case, the dictum changes to: The lesser the amount of mean annual precipitation, the greater the amount of nutrients.

Figure 3 shows a paired composition of two quite different situations. Figure 3 (a) is a view of the Sahara desert, with mean annual precipitation of 76 mm, definitely a superarid climate. Figure 3 (b) is a view of the Amazon rainforest, with mean annual precipitation of 2,600 mm, reflecting a decidedly humid climate. Experience has shown that while the soils of the Sahara desert are loaded with fresh nooutrients, the Amazon rainforest cannot count on the nutrients being in the soil, because they have already been leached from the profile through the passage of time.

Fig. 3 (a) The Sahara desert.

Fig. 3 (b) The Amazon rainforest.

The palm tree of the Sahara desert is able to tap the scant amount of soil moisture above the groundwater table and proceed with its physiological growth needs [Fig. 3 (a)]. Despite its apparent lushness, the Amazon rainforest has no other choice but to store the ecosystem's available nutrients within its abundant canopy and litter, to recycle them as appropriate [Fig. 3 (b)].

Within reasonable limits, just about any agricultural crop may be able to prosper in the Sahara desert, if only there was enough water to allow limited evapotranspiration to take place. Conversely, experience has shown that only a reduced number of agricultural crops are able to prosper in the Amazon rainforest. Artificial fertilization may prove to be self-defeating, because the frequent rain events in the humid forest are likely to readily wash away the applied nutrients, artificially enriching the adjoining streams in the process of *eutrophication*.

4. GEOMORPHOLOGY AND DRAINAGE

Enter the important science of geomorphology. Empowered with the force of gravity, Nature has created two types of drainages on the surface of the Earth: (1) *peripheral*, and (2) *non-peripheral*, i.e., basins situated inland. In geomorphological parlance, the former is referred to as an *exorheic* basin, while the latter is termed *endhoreic*.

Exorheic, or peripheral drainage basins are located in the periphery of continents. They carry the surface waters from headwaters to ocean, delivering their load of salts and closing the hydrologic cycle. Endorheic, or non-peripheral drainage basins do no such thing; instead, they drive themselves to a low spot in the landscape, where runoff collects and is subject to evaporation. Eventually, the moisture returns to the atmosphere, shortcutting the hydrologic cycle and leaving the load of salts somewhere within the basin confines, to sit there for the foreseeable future.

The consequences of this situation may not be altogether apparent. Peripheral basins are normally in *salt balance*; i.e., experiencing no salt accumulation, because the new salts generated over time are being continuously carried out to the ocean. On the other hand, non-peripheral basins defy salt balance, with the amount of salt deposited within their confines forever increasing as time continues to produce more salt. There is no salt flushing in a non-peripheral basin.

Peripheral basins thrive because the small amount of salt in the environment is technically background noise, an amount that is not increasing with time and that the ecosystem may have already gotten used to. On the other hand, non-peripheral basins are doomed; in geologic time, they eventually become salt deserts, unable to support the diversity of vegetation that would otherwise be the normal state of affairs in a peripheral basin.

The existence of an endorheic basin amounts to the proverbial luck of the draw. Given the harsh reality of tectonism, the larger the continent, the more the likehood that its centrally located, or middle regions, would be endorheic. Just about every continent has its share of endorheic basins. For example, in the United States, the *Great Basin* comprises most of the state of Nevada, half of Utah, substantial parts of California, and smaller portions of Arizona, Oregon, Idaho, Wyoming, and the states of Baja California and Sonora, in neighboring Mexico. The basin covers about 6.4% of the conterminous 48 states, not accounting for the small area in northern Mexico. Similar examples of large endorheic basins may be found in South America, Africa, and Australia, to say nothing of Asia.

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Fig. 4 The Great Basin.

It should not escape anyone's attention that the salt currently in the oceans most likely did not originate in endorheic basins. Endorheic basins collect salt, with some notable exceptions. It would take a cataclysm of near biblical proportions for any of that salt to be delivered to the oceans.

A case in point: About 15,000 years ago, ancient Lake Bonneville, in Utah, breached its northern edge and flowed into the Upper Snake river, in the Columbia river basin, eventually losing about 84% of its surface area while lowering the water surface elevation by about 400 m! [Click **-here-** to watch a 2012 video describing the event].

5. LAKE SALINITY

The salinity of the oceans hovers around 35‰, varying from 32‰ to 37‰, depending on local precipitation, evaporation, and runoff from nearby major sources of fresh water (the mouths of large rivers). Other terrestrial bodies of water, such as lakes, display a much broader range of variation in salinity, reflecting a complex array of factors, including geologic age, local and regional ecology and geomorphology and, more recently, antropogenic influence.

One observation may be drawn from the data. Lakes in arid regions tend to have high salinity, while lakes in humid regions display an opposite trend. Two cases are described here: (1) Great Salt Lake, in Utah; and (2) Lake Superior, one of the Great Lakes of North America; the latter straddles the border between the United States and Canada.

Great Salt Lake is an endorheic hypersaline lake, its salinity varying between 50 and 270‰, depending on location and lake level [For reference, at 25°C, 357‰ is the salinity concentration at which sodium chloride precipitation begins]. The great amount of salt in Great Salt Lake is due to the regional ecology and geomorphology, which contributes much salt-laden runoff from the adjacent landscape [Fig. 5 (a)]. Mean annual precipitation is about 280 mm, well within the arid range (200-400 mm) (**Ponce, 2023**).

In contrast to the Great Salt Lake, the Great Lakes of North America are *partially exorheic*. The Great Lakes drain into the Atlantic Ocean through the Saint Lawrence river and, therefore, feature largely fresh water. In fact, the water of Lake Superior, the most upstream of the Great Lakes, is among the freshest on Earth, with a very low salinity of only 0.063‰, about one-fourth of the background salinity of typical fresh waters. The markedly low salinity of Lake Superior is attributed to the following: (1) its partial exorheism, which washes out whatever low amount of salts it has; and (2) its draining a region with very few salts left in the geologically mature soil profile [Fig. 5 (b)]. Mean annual precipitation in the vicinity of Lake Superior is about 952 mm, clearly within the humid range (800-1600 mm) (**Ponce, 2023**).

We conclude that the salinity of a lake such as the Great Salt Lake (50‰ at its low end) is about 800 times greater than that of Lake Superior (0.063‰)! Part of this extremely large ratio may be attributed to the dearth of nutrients left in the soil profile in the vicinity of Lake Superior. Therefore, it should come as no surprise that it is among the purest fresh-water lakes in North America.

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Fig. 5 (a) The Great Salt Lake, Utah.

[Click on top of figure to expand]

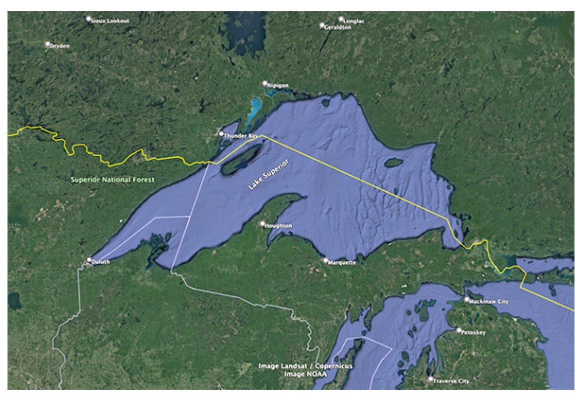

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Fig. 5 (b) Lake Superior, Ontario and Michigan.

In closing, lake salinity depends on: (1) the extent of its exorheism, and (2) the climate, ecology, and geomorphology of the surrounding environment.

6. SOILS AND DRAINAGE

The extra salt present in a given soil profile, which is mobilized by subsurface runoff into local and regional drainage, may originate in one of the following sources: (1) old natural salts; (2) new natural salts; (3) old artificial salts; and (4) new artificial salts.

1. *Old natural salts* are those typically of marine or lake origin, actually present in the soil, typically as salt layers, on account of the geologic history of the region [Fig. 6 (a)].

2. *New natural salts* are those that were originally *inside* the soil matrix and were mobilized by irrigation, the addition of moisture, biological weathering, and the partition of sand-sized particles.

3. *Old artificial salts* are those that are brought in with the irrigation water, typically from a distant place, labeled "artificial" due to their anthropogenic origin [Fig. 6 (b)].

4. *New artificial salts* are those that came with on-farm fertilization, due to the perceived need to increase the productivity of the irrigation enterprise.

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Fig. 6 (a) Old natural salts: Pampas de La Joya and Vitor valley, Arequipa, Peru.

[Click on top of figure to expand]

V. M. Ponce (2008)

Fig. 6 (b) Old artificial salts: Wellton-Mohawk main canal and drainage channel, Wellton, Arizona.

An enlightened irrigation project makes every effort to properly account for a *salt budget*. Old natural salts are to be avoided, if at all possible. New natural salts are estimated and accounted for based on the best available science. Old artificial salts are adequately accounted for in the salt budget. New artificial salts are handled in the best possible way to minimize leaching.

At this point, it bears to reiterate that the irrigation of arid lands effectively creates *new salts* by partitioning the relatively young soils to extract the useful salts (magnesium and potassium), while disposing of the waste salts (sodium and calcium), the latter to be removed by appropriate drainage [Fig. 6 (b)] (Rhoades and others, 1968). There is no way out of this predicament. The more arid the irrigation site, the more waste salts will be mobilized, creating the need to be eventually removed from the premises.

7. THE DESIGN OF NATURE

The rivers of the Earth are responsible for carrying the *surplus salts* to the ocean. Water's dipole moment ensures that the salts are picked up by both subsurface and surface runoff. Once dissolved in the runoff, the salts remain there due to their high solubility, until such time that the rivers deliver their load to the oceans. That is what Nature intended, and that is what has taken place through eons.

Without runoff, the delivery of waste salts to the oceans would not have been possible. But runoff is always there, particularly for peripheral basins in salt balance [A basin in salt balance is one with no significant salt accumulation over time]. About 40% of the precipitation (rainfall) falling onto the Earth's land surface actually makes it to the oceans, 28% as surface runoff and 12% as subsurface runoff (L'vovich, 1979; **Ponce, 2006**).

Runoff has a salinity concentration, i.e., the dissolved excess salts that were picked up somewhere upstream. The concentration varies with a gamut of factors, including local and regional geology, geomorphology, hydrology, and ecology. However, one thing is clear: The concentration generally *increases* in the downstream direction as more salts are added to the runoff, while all kinds of evaporation continue to take place. While a stream headwater may show an almost pristine quality, by the time the stream flows into the ocean, its salinity is bound to have increased substantially. This fact led Pillsbury (1981) to argue that as a river flows from headwaters to ocean, its increase in salinity due to accumulated evaporation has a distinct natural flavor (**Pillsbury, 1981**).

The partnership of water and salt having been established, we now turn our attention to the water, i.e., to the surface runoff. On a global average basis, we have noted that about 40% of terrestrial precipitation is actually converted to surface runoff and delivered to the oceans. This figure, referred to as *runoff coefficient*, is a temporal and spatial average. Across the world, runoff coefficients vary widely, from as low as 2% in some extremely arid regions to 93% in certain very unusual geological settings (L'vovich, 1979). Consider, for example, the following statement: A runoff coefficient of 0% means 100% evapotranspiration, while a runoff coefficient of 100% means 0% evapotranspiration!.

In Nature, runoff coefficients have a tendency to increase with the amount of environmental moisture. In arid regions, they are typically less than 20%, while in humid regions they may be as high as 60%. For comparison, we note that the runoff coefficient of the Amazon river basin, measured at Óbidos, Brazil, near the river's mouth, is about 51%.

Terrestrial and lake/reservoir evaporation, together with plant transpiration, constitute total *evapotranspiration*. The latter has the net effect of concentrating the salts, since these are left behind in the water that remains (**Pillsbury, 1981**). It follows that streams in arid regions have generally higher salt concentrations than streams in humid regions. However, the actual amount of salts carried by streams in humid regions, measured *in terms of weight*, may rival and even exceed those of arid regions.

A global value of runoff coefficient of 40% means that the remaining 60% was actually consumed and returned to the atmosphere by: (1) land evaporation, (2) water-body evaporation, and (3) plant transpiration. For individual cases, the actual percentages remain to be determined by a suitable hydrologic water balance. The actual amounts are significantly influenced by the local and regional climate, and, in certain unusual cases, by geomorphology.

A case in point: The runoff coefficient of the Upper Paraguay river, measured at Porto Murtinho, in Mato Grosso do Sul, Brazil, near its mouth at the confluence with the Apa river, should be above $K = 0.2$ if the local subhumid climate were to be any indication [Fig. 7 (a)]. A value of $K = 0.22$ has been calculated at Cáceres, immediately upstream of the Pantanal; however, the actual value at Porto

Murtinho is $K = 0.08$. This substantial reduction in runoff coefficient is due to the regional presence of a continental delta, created by a tectonic uplift feature rising about 40 m, with a focal point at Fechos dos Morros, literally *Closing of the Hills* in the Portuguese language [Fig. 7 (b)]. This continental delta is responsible for the existence of the Pantanal of Mato Grosso, which, with a surface area encompassing 136,700 km^2, is regarded as the largest wetland in the world. In this case, geomorphology has acted to convert surface runoff to evapotranspiration on a grand scale (**Ponce, 1995**) [Click **-here-** to watch a 1993 video describing the Pantanal of Mato Grosso].

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Fig. 7 (a) Porto Murtinho, in Mato Grosso do Sul, Brazil, surrounded by a polder for flood control purposes, established ca. 1992.

[Click on top of figure to expand]

V. M. Ponce (2008)

Fig. 7 (b) Fecho dos Morros, in Mato Grosso do Sul, Brazil, literally *Closing of the Hills*, a tectonic uplift feature responsible for the existence of the Pantanal.

8. THE DESIGN OF HUMANS

Enter humans. For the past more than 100 years, contemporary human societies have been engaged in altering the water balance of a basin by converting runoff into evapotranspiration by way of irrigation. There is a lofty aim to this endeavor: To help sustain human populations by the cultivation and harvest of additional amounts of food and fiber.

A common belief is that the water resources of a region are *precious*, and should not be wasted by letting them flow into the ocean. Irrigation converts water that would otherwise flow into the ocean into additional evapotranspiration. This has the net effect of **reducing** the amount of runoff and **increasing** the concentration of salts in the drainage waters.

Over the years, irrigation has seemed to work well, and it has led to some successes, many of which have been documented in the literature. In general, however, irrigation is not without its pitfalls (American Society of Civil Engineers, 2012). All river water carries salts which are left behind at the time of conversion of runoff to evapotranspiration. Every drop of water consumed by plants leaves behind *an iota of waste salt*. These salts accumulate over time and, therefore, need to be disposed off properly if the irrigation enterprise is to continue.

Not all irrigation projects produce a comparable amount of waste salt. The quantity of waste salts tends to be much larger in arid regions than in humid regions. A well managed irrigation project develops a salt budget to account for all the sources of salts, calculates the amount of salts that are to be wasted, and formulates a strategic plan for salt removal and disposal.

After irrigation projects were developed in earnest, the realization of the need for salt disposal encouraged the development of the field of *irrigation drainage engineering* [Fig. 8 (a)]. At great expense, the waste salts may be removed from the premises, but only at the cost of increasing the salinity of the flow (channel, stream or river) that is charged with removing the waste salts and conveying them to their final destination. There does not seem to be a way out of this predicament!

The disposal problem may be somewhat manageable when the irrigation project site is reasonably close to the nearest ocean; say, along the coast, or within a short distance from it. Otherwise, a difficult problem of waste salt disposal arises, one that initially may be characterized as a technical problem, but that eventually becomes a political problem. Two examples in California, those of the San Joaquin valley (irrigated since the 1800s) and the Imperial valley (irrigated since the early 1900s) help describe the experience with irrigation drainage waters (**Ponce, 2005**; **2007)**.

Rather than sending the waste salts all the way to the ocean, a solution may be to store them in evaporation ponds, where they may remain forever hidden from general view [Fig. 8 (b)]. However, this solution is not good in the long run, because the stored waste salts are bound to eventually seep into the local/regional groundwaters and contaminate them with additional new salinity (**Pillsbury, 1981; Extract**).

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Fig. 8 (a) Irrigation and drainage canals, Wellton-Mohawk Irrigation District, Wellton, Arizona.

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Fig. 8 (b) South evaporation pond, Tulare Lake Basin, Kings County, California.

Prior to the advent of irrigation, there were no extra salts to contend with. The system was referred to as *dryland farming*, or *dryland agriculture*, which relied solely on the water and moisture provided by Nature. Productivity was comparatively low, but water harvesting systems and other similar low-cost technologies could be implemented to reduce the difference between what Nature could provide and what humans could aspire to for economic reasons.

Given enough time, likely to be measured in centuries, irrigation could end up replacing healthy peripheral basins with pockets of salt-infested endorheic basins, purportedly to hold for the foreseeable future the waste salts produced by irrigation. The environmental impact of such change, likely to encompass many generations, will prove to be very difficult to manage.

Case study: The Salton Sea, in California. Waste salts have been collected in this below-sea-level (-96 m) large repository of agricultural drainage for a little more than a century. An effective solution for the many problems that the Sea faces, and one that will satisfy all stakeholders, will very likely be prohibitively expensive, given that too much time has gone by and large amounts of salt have accumulated. Now that lithium has been discovered in the vicinity, the time may come when agricultural interests are no longer a priority in the region. However, the Sea and its mixed brew of salts and other constituents stand to remain in place for the foreseeable future.

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Fig. 9 The Salton Sea, a below-sea-level (-69 m) very large repository of agricultural drainage, in between Imperial and Coachella valleys, Imperial and Riverside counties, California.

9. SUMMARY

The findings of this article may be summarized in the following points:

1. Vegetative ecosystems are known to be highly selective in their use of the four common salt cations; they will readily uptake magnesium and potassium, while largely wasting sodium and calcium.

2. Once in ocean waters, calcium (Ca+) is taken out of solution by biological organisms for the building of shells and skeletons or by chemical precipitation, which leaves sodium to constitute the lion's share of the four common salt cations in ocean waters.

3. Water has a large dipole moment, a property of its molecular structure that enables it to dissolve almost anything. The dipole moment arises because oxygen is more negatively charged than hydrogen; thus, oxygen pulls in the shared electrons, increasing the electron density around itself.

4. The greater the amount of mean annual precipitation, the greater the amount of leaching of the underlying soils. Therefore, subhumid to superhumid climates find their soils devoid of nutrients.

5. The smaller the amount of mean annual precipitation, the lesser the possibility of leaching of the underlying soils. Therefore, semiarid to superarid climates find their soils filled with nutrients.

6. Exorheic, or peripheral drainage basins carry the surface waters from headwaters to ocean, delivering their load of salts and closing the hydrologic cycle. Conversely, endorheic, or non-peripheral drainage basins do no such thing; instead, they drive themselves to a low spot in the landscape, where runoff collects and is subject to evaporation.

7. Lakes in arid regions tend to have high salinity, while lakes in humid regions display an opposite trend.

8. The extra salt present in a given soil profile, to be mobilized by subsurface runoff into local and regional drainage, may originate in one of the following sources: (1) old natural salts; (2) new natural salts; (3) old artificial salts; and (4) new artificial salts.

9. The irrigation of arid lands effectively creates new salts by partitioning the relatively young soils to extract the useful salts (magnesium and potassium), while disposing of the waste salts (sodium and calcium), the latter to be removed by appropriate drainage.

10. As a stream or river flows from headwaters to ocean, its increase in salinity due to the accumulation of evaporation has a distinct natural flavor.

11. Not all irrigation projects produce a comparable amount of waste salt. The quantity of waste salts tends to be much greater in arid regions than in humid regions.

12. The salt disposal problem may be somewhat manageable when the irrigation project site is reasonably close to the nearest ocean, say, along the coast, or within a short distance from it.

10. OUTLOOK

Irrigation is shown to be a mixed bag. On one hand, the irrigation of arid lands may result in a very productive enterprise; on the other hand, it is very likely that the increase in productivity will be coupled with a comparable increase in the amount of waste salts, which would need to be disposed of properly, usually at great expense. Barring effective disposal of salt waste, the local environment will be saddled with new salts and these will invariably result in the degradation of the landscape. It is proposed here that societies must learn to pay for the adequate disposal of waste salts produced by irrigation. To the extent that this article throws additional light on this important issue, it will have accomplished its aim.

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