Chapter 89
Geo-Engineering South Australia: The Case of Lake Eyre

Viorel Badescu, Richard B. Cathcart, Marius Paulescu, Paul Gravila, and Alexander A. Bolonkin

89.1 Introduction

Australia is the world's driest permanently inhabited continent and it has the most variable precipitation with periods of widespread drought (Sohn, 2007). "Afflicted" by a climate dominated by the subtropical high pressure belt which encloses high pressure air systems that move from the west Coast to the east Coast above the ocean isolated terrestrial ecosystem, Australia is a vast dry-land region; ~75% of the continent – approximately ~3,030,000 km^2 – is classed as either arid or semiarid. Naturally, the boundaries of these continental climate regions are neither static nor obviously abrupt. During the coolest period of the year (Winter: May–October), the high pressure systems pass slowly over central Australia's land in an air belt extending from 29° to 32°S Lat and often remain stationary for several days, causing orographic precipitation on the east coast mountains. Studies show precipitation for the nation varies from summer dominant rainfall in the north to winter dominant rainfall in the south, making the resulting available flowing freshwater resource very problematic (Fleming, 1995). During the warmest period of the year (Summer: November–April), the subtropical high-pressure systems belt normally shifts offshore, flowing over the Indian Ocean at 37° to 38°S Lat. Pigram (2006) offers the most comprehensive assessment currently available. Currently, the episodic Lake Eyre is Australia's largest playa and lowest elevation. The annual rainfall on Lake Eyre amounts to ~125 mm (4.9 in) with an average annual pan-evaporation of ~3,800 mm (149.6 in); northeast of Lake Eyre the rainfall averages ~500 mm (19.7 in) and pan-evaporation is ~2,400 mm (94.5 in). The Lake Eyre Basin, ~1,140,000 km^2, or ~15% of all Australia, exhibits ephemeral stream channels, aeolian dunes, gibber plains and bare bedrock. 21st century human residents of Lake Eyre Basin number fewer than 60,000 persons. Lake Eyre is comprised of two depositional basins, the North Basin, which is the deepest, has an estimated plane surface area of ~8,400 km^2 (3,218 mi^2) and the South Basin is ~1,200 km^2

V. Badescu (✉)
Candida Oancea Institute, Polytechnic University of Bucharest, Bucharest, Romania
e-mail: badescu@theta.termo.pub.ro

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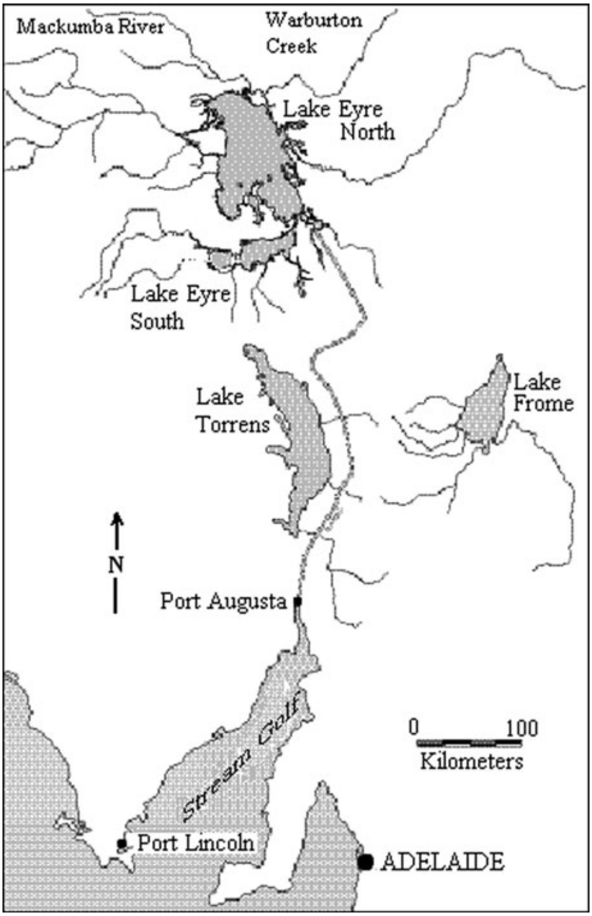

Fig. 89.1 Port Augusta to Lake Eyre Pipeline Corridor. A slightly different course might prove better if only the South Basin is to be filled at the Lake Eyre terminal south of the proposed Goyder Channel Tension Textile Dam. (Source: Fereidoun Ghassemi & Ian White, 2006, Fig. 7.5, p. 146)

(460 mi^2) (Fig. 89.1). It can contain about 27 km^3 of water at 9.5 m (31.1 ft) below global sea level. The brackish water level in Lake Eyre is unregulated and, owing to rare storms, can rise rapidly in a matter of months with flows of 5,000 to 10,000 m^3/s; during 1974 water flowed from the –15 m-deep North Basin into the South Basin but during 1984 the South Basin overflowed into the North Basin. Present-day Lake Eyre (28.3°S Lat. by 137.2°E Long.) is situated in the "hot dry summer, cold winter" Australian Climatic Zone, meaning the average January maximum air temperature >30°C (>86°F), three o'clock afternoon water vapor pressure is <2.1 kPa and average July mean air temperature exceeds 14°C (57°F). Kingsford (2006) offers a comprehensive overview of watered arid lands worldwide, including the Lake Eyre Basin.

Though macro-engineering is a rather recent subject of public interest (Badescu, Cathcart, & Schuiling, 2006), proposals for the flooding of Lake Eyre with water from the ocean (via Spencer Gulf's Port Augusta) have become a staple of conversation in ordinary and national political circles since about 1883 (Boia, 2005). Filled to present-day ocean level, the Eyre Seawater Reservoir (ESR), North and South basins combined, would hold more than 200 km^3. "By contrast, the deepest historical filling held 30 km^3" (DeVogel, Mageeb, Manleya, & Millerc, 2004). Ghassemi and White (2006) offer the best historical account of some schemes for the creation of an artificial inland sea. The slope of the canal would be less than 3 cm/km, and it was doubtful if the water would flow in such a canal. Excavation of a canal from Port Augusta (32°S Lat. by 137°E Long.) at the head of Spencer Gulf to Lake Eyre, a distance of ~320 km (198.8 mi) with a maximum ridge elevation of <60 m (196.8 ft) (see Fig. 89.1) may well exceed 50 GUSD (billions USD). In this chapter a macroengineering project is proposed, which exploits technologies that have the potential to enliven the arid region surrounding Lake Eyre.

89.2 Aims of the Macroproject

Bringing seawater to Lake Eyre has been discussed since at least 1883 but here, for the first time ever, we offer technical and economical details. The macroproject will utilize ~0.11% of Australia's territory that is below present-day global sea level, most of which is entirely unsettled and has a small annual GDP economic impact, even though it is also often described as picturesque (Gibbs, 2006). This study does not provide final macroproject solutions; there are additional problems that must be investigated before any political and financial decision-making. Some of these problems are enumerated in the section entitled Ecological, Cultural and Social Consequences.

The macro-project assumes Lake Eyre is permanently filled with seawater. When Lake Eyre is full, and its ASL is +5 m (16.4 ft), Lake Eyre covers an area of ~19,600 km^2 (7,509 mi^2) and contains ~215 km^3 of saline liquid. It might be best to envision Lake Eyre with an artificial level of –3.5 m (11.48 ft) ASL, an area of 9,920 km^2 (3,800 mi^2) and a volume of 75 km^3(Fig. 89.2). Even a lower filling level such as –6 m ASL, ~55 km^3, constitutes an ambitious macro-project aim. Such a vision offers a Lake Eyre where both the North and South basins are filled constantly and joined through the Goyder channel. The water volume and the surface area of a full Lake Eyre is denoted V_{lake} and S_{lake}, respectively. Here we accept $V_{\text{lake}} = 75\,\text{km}^3$ and $S_{\text{lake}} = 9,920\,\text{km}^2$.

The source of incoming water into the lake may be non-continuous (massif rains, occurring at a random time interval t). Lake Eyre South is known to have filled in 1938, 1955, 1963, 1968, 1973, 1974, 1975, 1976 and 1984. In 1984 Lake Eyre South overflowed to Lake Eyre North. In 1974 water flowed from Lake Eyre North to Lake Eyre South between March and October when an equilibrium level was obtained. Groyder Channel is a 15 km (9.3 mi)-long topographic depression that links Lake Eyre North and South (see Fig. 89.1). The width as well as lowest elevation of the

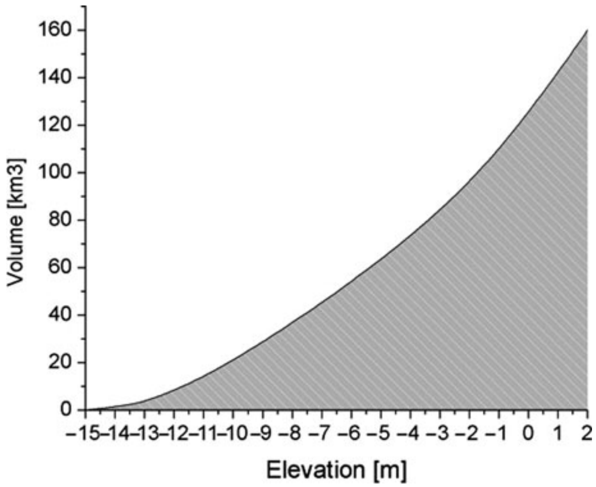

Fig. 89.2 Volume/elevation curve of the Lake Eyre

Goyder Channel, named for George Woodroffe Goyder (1826–1898), changes with each significant flooding event. In this study we accept $t = 8$ years as an average value of the observed data (McMahon et al., 2005).

89.3 Macroproject Components

Long term flooding of Lake Eyre may have important consequences for the sparse human population nearby. In terms of aims, this macroproject proposes the ESR as a center of a region of biosaline agriculture. Other possible benefits are briefly enumerated in the section entitled Seawater Irrigation Macroproject.

In terms of tools, the project is based on three ideas. First, seawater is transported by flexible pipes rather than by a single canal. Second, use of photovoltaic (PV) cells is envisaged to ensure the electricity necessary to pump the seawater. Third, artificial covering of the Lake will greatly diminish evaporation. All of these tools were previously proposed and studied by various groups of researchers. Some details and critical notes follow. The study involves some engineering and economic calculations. However, these evaluations are very rough, not taking into account the many unknown and missing parameters involved.

89.3.1 Pipeline and Pumps

There is an Australian precedent plan for a seawater pipeline (Allan, Banens, & Fielder, 2001). They mention that the Water Corporation of Western Australia proposed a 348 km (216 mi)-long Esperance to Kalgoorlie seawater pipeline as a major water supply option.

Our proposal uses low pressure and cheap pipes by having multiple pumping stations along the route. If a pipe ruptures, the damage should be easily repaired

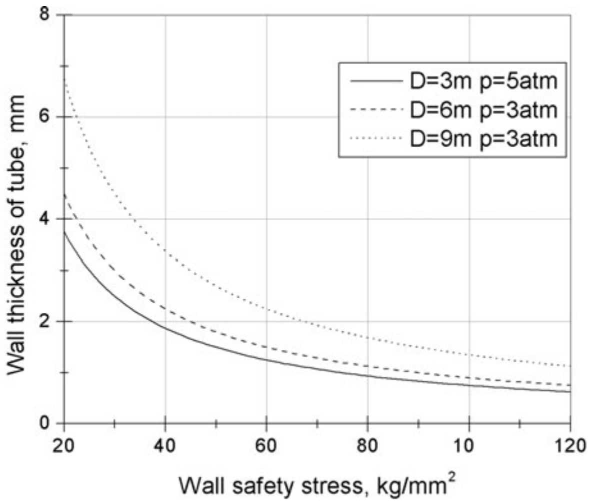

Fig. 89.3 Tube-wall thickness via wall safety tensile stress for different tube diameters and water pressures

without creating environmental problems. We suggest the pipe walls could be made mainly of inexpensive waterproof textile. It is possible to employ multiple tubes instead of merely one, two or more “pipelines” transporting seawater to Lake Eyre in a special zoned land-use corridor. A wide-diameter hydraulic tube is more expensive but such a pipe, hose or tube has the advantage of decreasing greatly the pressure loss and increases significantly the efficiency and decreases the friction loss and pump power. Below, is the equation for tube wall thickness computation:

$$\delta = \frac{pD}{2\sigma} \tag{89.1}$$

where δ is tube-wall thickness; p is water pressure and σ is safety tensile stress. The computation’s result is presented in Fig. 89.3. The tension textile tube must be supported along its entire length by a special chute, a cradle-like trough or discrete air-inflated pillows. (Earthquakes in the region are not a known infrastructure hazard.)

The source of seawater for Lake Eyre may be a continuous or non-continuous macro-engineered addition from the Indian Ocean. Lake Eyre’s South basin lies 356 km (221 mi) from Port Augusta. Cost-free seawater can be extracted from Spencer Gulf. The duct length and diameter is denoted L_{duct} and D_{duct}, respectively, while its maximum elevation above sea level is H_{duct}.

The seawater volume flow rate through the duct is Q_{sw}. The duct includes some pumps (main parameters: consumed pumping power P_{p}). The necessary power is provided by PV cells (collection area A_{pv}, produced electrical power P_{pv}). The speed W_{sw} of seawater in the duct of diameter D_{duct} is given by:

$$w_{\mathrm{sw}} = \frac{4Q_{\mathrm{sw}}}{\pi D_{\mathrm{duct}}^2} \tag{89.2}$$

The power P_{pump} required to impel the seawater within the duct is obtained from:

$$P_{\text{pump}} = g\rho_{\text{sw}} Q_{\text{sw}} H/\eta_{\text{p}} \tag{89.3}$$

In Equation (89.3), $g = (9.78\,\text{m/s}^2)$ is gravitational acceleration, $p_{\text{sw}} = (1{,}030\,\text{kg/m}^3)$ is the density of the seawater, H is the hydraulic head and $\eta_{\text{p}}(\cong 0.75)$ is the efficiency of the electric pump. The hydraulic head is obtained by summing the highest altitude of the duct $H_{\text{duct}}(\approx 60\,\text{m})$ with the lost pressure height H due to friction:

$$H = H_{\text{duct}} + \Delta H \tag{89.4}$$

Only linear pressure losses are considered next and:

$$\Delta H = \lambda \frac{L_{\text{duct}}}{D_{\text{duct}}} \frac{w_{\text{sw}}^2}{2g} \tag{89.5}$$

where λ is the linear pressure loss coefficient given by:

$$\lambda = \begin{cases} \dfrac{1}{\sqrt[4]{100\text{Re}}} & \text{for} \quad \text{Re} < 10^5 \\ 0.0032 + \dfrac{0.211}{\text{Re}^{0.237}} & \text{for} \quad \text{Re} > 10^5 \end{cases} \tag{89.6}$$

where the Reynolds number is defined by

$$\text{Re} = \frac{w_{\text{sw}} D_{\text{duct}}}{\nu_{\text{sw}}} \tag{89.7}$$

with ν_{sw} the kinematic viscosity of seawater. The constant value $\nu_{sw} = 13 \cdot 10^{-4}/p_{sw}$ is adopted in this study. The specific power for a 1 m^3/s flow is:

$$P_{\text{specific}} = P_{\text{pump}}/Q_{\text{sw}} = g\rho_{\text{sw}} H/\eta_p \tag{89.8}$$

Numerical results for pipe diameters of 3 m (9.8 ft), 6 m (19.7 ft) and 9 m (29.5 ft), respectively, and water-speeds of 2 and 4 m/s, respectively, are presented in Table 89.1. Figure 89.4 shows the dependence of the specific pumping power (in MW per m^3/s) on water-speed and pipe diameter. A first conclusion is that using a large diameter tube, low pressure, low water-speed is much more energy effective. We identify the scheme no. 5 (marked with an ·) as best suited for our project. It is clearly better to construct two units of this type than to double the speed of water. More fine-tuning for optimizing the pumping system can be made only when exact price specifications for all components are known.

Table 89.1 Parameters for Port Augusta to Lake Eyre Pipeline

Number	Diameter (m)	w_{sw} (m/s)	Q_{sw} (m^3/s)	Hydraulic head (m)	P_{pump} Total (MWe)	Number of stations	Δp (atm)	P_{pump}/Station (MWe)
1	3	2	14	270	53	9	3	5.8
2	3	4	28	830	313	28	3	11.2
3	6	2	56	156	120	15	1	8.0
4	6	4	113	411	620	41	1	15.1
5	9	2	127	120	204	12	1	17.0
6	9	4	254	282	956	28	1	34.1

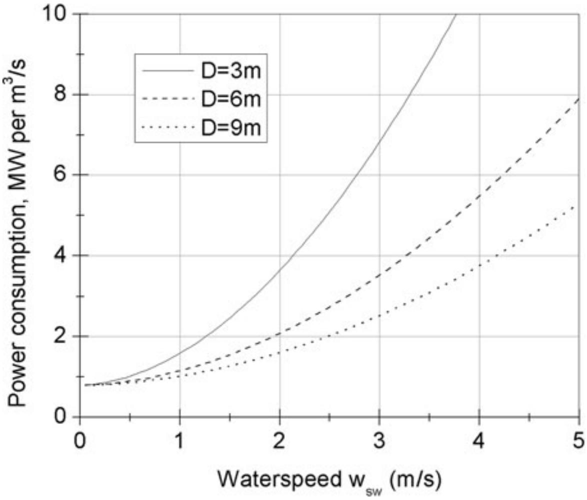

Fig. 89.4 Specific pumping power dependence on water speed and pipe diameter

89.3.2 Photovoltaic Power Plant

Kurokawa (2006) touts the benefits of carpeting desert regions with photovoltaic cells. Essentially, his proposals differ little from those made by TREC Australia (DESERTEC, 2008). Both TREC Australia and Kurokawa recognize that Australia's deserts are perfect places for such vast power generating installations.

The average annual temperature varies from 21°C (69.8° F) south of the Basin to 24° C (75.2°F) north of it, and the average maximum temperatures are 18°C (64.4°F) and 24°C (75.2°F) respectively in July, and 36°C (96.8°F) and 39°C (102.2°F) in January. The annual hours of sunshine vary from 3,250 to more than 3,500 and the average global radiation is 6 KWh m^{-2} day^{-1}. Surprisingly, the literature is poor on detailed solar radiation data in the vicinity of Lake Eyre. In Table 89.2 there are some data that could be used as a starting point in computations. Here the following yearly averaged daily solar global irradiation on a horizontal plane around Lake Eyre is adopted: $G_{day} = 21.6\,\mathrm{MJm^{-2}\ day^{-1}}$, which is close to the

Table 89.2 Monthly mean of daily global solar irradiation [KWh/(m^{-2} day^{-1})]

Location	Dry-Creek	Moomba	Woomera	Gladstone
Lat. and Long.	34.83S, 138.58E	28.10 S, 140.20 E	31.52 S, 137.17 E	33.28 S, 138.37 E
Type	P	U	U	U
Jan	8.03	8.25	7.42	6.86
Feb	6.98	7.90	6.97	6.53
Mar	5.66	6.97	6.00	5.81
Apr	4.95	5.00	4.81	5.33
May	2.71	4.18	3.53	4.39
Jun	2.29	3.78	3.08	4.00
July	2.43	3.75	3.36	4.28
Aug	3.32	4.18	4.14	4.86
Sep	4.61	5.52	5.28	6.06
Oct	5.57	7.10	6.36	6.50
Nov	6.97	7.85	7.08	7.03
Dec	7.69	8.14	7.50	6.81
Yearly Mean	5.10	6.06	5.47	5.69

value estimated in Table 89.2 for Moomba. The yearly solar global irradiation G_{year} is:

$$G_{\text{year}} = 365 G_{\text{day}} \tag{89.9}$$

The energy provided per unit surface area by PV cells during a year, $E_{PV,\,\text{year},\,1}$ is given by:

$$E_{PV,\text{year},1} = G_{\text{year}} \eta_{PV} \tag{89.10}$$

where η_{PV} is PV cell efficiency (yearly average). In computations we use a rather high (optimized) value $\eta_{PV} = 0.15$ (Badescu, 2006).

In dimensioning the solar power plant, we use the earth surface – level solar irradiance S_c (of about 1 kWm^{-2}) to calculate the collector surface area in order to match the power specifications of the pumping system. Keep in mind that we are constructing a system consisting of a generator and a consumer, without energy storage or other essential power regulation devices. The consumer (pumps) will be designed so that they can operate under partial loads with good efficiency (by example, each station may be fitted with a tandem of (different-sized) pumps so that the one, or the other, or both are automatically switched on according to conditions). The area covered by PV panels will be:

$$P_{\text{pump}} / S_c \eta_{PV} \tag{89.11}$$

For example, for generating 204 MW of electricity, as the system no. 5 in Table 89.1 demands, the area would be 1,36·10^6 m^2. The top area (section) of the pipe is $D_{\text{duct}}L_{\text{duct}} = 3.2 \cdot 10^6\,\text{m}^2$, it means that the PV system may even be fitted on top of the duct. A solution using thin film technology (second generation solar cells) with smaller efficiencies ($\sim$0.08) but cheaper, can also be considered. Future PV technologies may greatly improve the feasibility of this component. The drawback of using only solar generation without energy storage is of course that the pumping system is working full power only a few hours per day, in good weather. The energy produced in a year is $E_{(PV,\text{year})} = A_{PV}E_{(PV,\text{year},1)}$, equals $1.6{\cdot}10^9$ MJ (440 GWh), as for our example. This would pump roughly 1 km^3 of water per year (for one unit, but more units can be build). At nominal power day and night the same pump would do $\sim$ 4 km^3 of water per year.

89.3.3 Lake Eyre Lid

A global warming mitigation by reduction of outgoing longwave radiation through large scale surface albedo enhancement of deserts using white plastic polyethylene film was proposed in 2003 (Gaskill & Reese, 2008). We wish to lid a large, saline water body, in order to decrease evaporation and freshwater loss.

One denotes by $q_{\text{evap},1}$ the rate of evaporated water per unit surface (units: cubic meter per square meter and per second). Then:

$$Q_{\text{evap}} = q_{\text{evap},1}(1 - x)S_{\text{lake}} \tag{89.12}$$

Here x is the fraction of lake surface covered ($x = 1$ means the whole surface is covered and consequently, no evaporation occurs).

Earlier estimates show that the annual rainfall on Lake Eyre amounts to $\sim$125 mm (4.92 in) with an average annual pan-evaporation of $\sim$3,800 mm (149.6 in). The difference between these two quantities gives the net specific evaporation rate. The measure of evaporation used in a recent report (McMahon et al., 2005) is the mean annual area potential evapotranspiration (APET). APET values vary from $\sim$1,000 mm/year in the south of the Lake Eyre Basin to >1,500 mm/year in the north (Fig. 89.5 for monthly evaporation rates). For an average value of 1,250 mm/year, one finds $q_{(\text{evap},1)} = 0.396 * 10^{-7}\text{m}^3/\text{m}^2/\text{s}$.

One assumes that:

$$Q_{sw} = zQ_{evap} \tag{89.13}$$

where z is a fraction ($z = 1$ means that the water flow rate coming from the ocean equals the evaporated water flow rate).

Our first proposal consists of a floating lid made from thin polyethylene sheeting, like the “bubble-wrap” used by shipping industry packagers, with 100% water imperviousness. It can be manufactured as modules, “carpets” of 100$-$1,000 m^2 of very low density material with tougher plastic margins (frame), which can be assembled together with clips and tethered to the seabed. Rainwater accumulating atop the

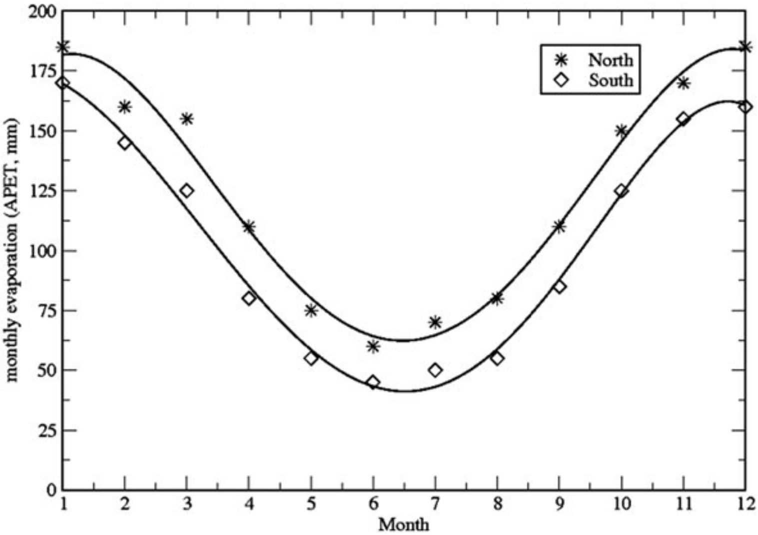

Fig. 89.5 Eyre North and South monthly evaporation rates

mat is allowed to drain through small holes so that the lid stays afloat. The lid covers 60−75% of the lake surface, leaving a couple of kilometers off the shores open. This greatly reduces adverse ecological and aesthetical impact, however important ecological concerns will remain and require further studies. Evaporation consists of precious freshwater, so preventing it is a main part of this proposal. It goes along with albedo enhancing on large scale which is benefic for the climate. Most researchers agree that water evaporated from the Eyre region, even if the Lake would be filled, is lost and does not induce climatic changes and precipitations on target areas.

If the cost per square meter is not kept down by ingenious design and maybe on-site production, the total cost may well become outlandish. While the lid itself can be very light and cheap (cents per m^2), the frame adds to the module cost. Also, installing them may be a logistic nightmare. We adopt $c_{\text{cover},1} = 1\,\text{USD}/\text{m}^2$, where $c_{\text{cover},1}$ is covering cost per unit surface area. This means that covering the lake is by far the most expensive part of the project, not only as investment, but also in terms of maintenance.

We mention that there are also other means to cover the body of liquid, namely, floating white plastic balls. The material costs will be about the same as the sheeting but deployment will be much easier. But, hollow balls will be much more affected by wind than rim-anchored flat plastic sheeting; they can also pile up on the shoreline. Then, they have to be returned to the water's surface by diligent macroproject caretakers. Since we will be using a lot of plastic, the bulk manufacturing costs should be low since bidding will offer the prospect of worldwide suppliers. While the sheeting is impermeable and causes 100% seawater retention (zero evaporation) the floating balls will (theoretically) cause ~70% seawater retention.

89.4 Investment Costs

For each of these macro-engineered components (i.e., covering the lake, ducts and pumping) there are two obvious associated costs:

- Costs of construction (investments). They are proportional with the main extensive quantity of each component. These costs refer to covering the surface xS_{lake} of the lake, building the duct Spencer Gulf-Lake Eyre, including the pumps and the PV cells (this cost is a function of L_{duct}, H_{duct}, D_{duct}, Q_{sw}, material of the duct).
- Costs of operation and maintenance. They are proportional with the main extensive quantity of each component. They are related to seawater pumping and maintenance of the floating covering system.

The duct cost increases by increasing the pipe diameter, as expected. Obviously, it depends on the tensioned duct material, with composed fabric the least expensive solution. The same feature exhibits the cost of installing the duct, but in this case the dependence on duct diameter is weaker. The cost of the pumps comprising the pumping installation decreases by enlarging. However, it is obvious that the larger contribution to the macroproject cost is provided by covering Lake Eyre.

The cost of the duct, the PV cells and of the electric pumps enabling steady seawater shifting, are estimated. The cost c_{duct} of the conducting tube is given by:

$$c_{\text{duct}} = c_{\text{duct},1} L_{\text{duct}} \tag{89.14}$$

where $c_{\text{duct},1}$ is the cost of a unit length of duct. Similarly, the cost of installing the tube, $c_{\text{inst,duct}}$ is given by:

$$c_{\text{inst,duct}} = c_{\text{inst,duct},1} L_{\text{duct}} \tag{89.15}$$

where $c_{\text{inst,duct},1}$ is the cost of installing a unit length of duct. The unitary costs depend, of course, on various factors, such as the duct diameter D_{duct} as well as the material of the duct.

The cost of the pumping installation, C_{pump}, is obtained from:

$$C_{\text{pump}} = P_{pump} c_{\text{pump},1} \tag{89.16}$$

where $c_{\text{pump},1}$ is the cost a pump of unit power.

The cost c_{PV} of the PV cells is obtained from the cost per Watt of the PV cells, $c_{(PV,W)}$, and the total installed power:

$$c_{PV} = c_{PV,W} P_{PV} \tag{89.17}$$

Today, PV cell prices are about 3.0 USD/W for thin film cells ($\eta \sim 0.08$), and 4.8 USD/W for monocrystaline cells ($\eta \sim 0.12 - 0.15$).

Table 89.3 Cost estimations

Component	Cost/Unit	Units	Total MUSD	Totals
Fabric Duct D = 9 m	900 USD/m	360,000 m	324	One complete pumping unit for 1 km^3/year: 1611 MUSD
Installation	400 USD/m	360,000 m	144	
Pumps	800 USD/KW	204,000 kW	163	
PV Plant	4800 USD/KW	204,000 kW	980	
Lidding 60%	1.0 USD/m^2	6000 km^2	6000	6000 MUSD

To evaluate the financial magnitude of partially covering Lake Eyre we have to calculate:

$$c_{\text{cover}} = xS_{lake}c_{\text{cover},1} \tag{89.18}$$

An estimation of the investment costs is summed in Table 89.3. We also estimate that the pumping systems will be largely maintenance-free (cost $\sim$ 2% /year), but the floating lid will require higher maintenance (cost $\sim$ 10% /year). In order to effectively raise water levels and transform Lake Eyre from ephemeral to permanent, more (3−5) such pumping units have to be installed, raising the total cost of the project to 12−14 GUSD and maintenance costs to about 0.8 GUSD/year.

Finally, note that the computations reported here are very rough and in actual practice the costs of the macro-project may be higher.

89.5 Seawater Irrigation Macroproject

In what follows, some considerations on biosaline agriculture are now addressed. While we do not expect that this sector alone will make for the huge costs of this macroeconomic project, it is a good example of an activity enabled by this project, with potential to enhance the economic viability of the region.

Biosaline irrigation requires no special equipment. Existing test farms have tried either flood irrigation of large basins or broadcast seawater (Glenn, Brown, & O'Leary, 1988). Seawater agriculture needs ~35% more irrigation fluid when crops are grown using seawater than conventional crops using freshwater. The main problem is that the land evaporates sweet water and the land's soil salinity will increase year by year. However, generally, there are no insurmountable macroengineering problems associated with biosaline agriculture (Ozturk, Waisel, Khan, & Gork, 2006).

Input values were suggested from the Project Ras al-Zawr (located in Saudi Arabia, north of Jubail on the Persian Gulf) where *Salicornia bigelovii* is cultivated (SaudiAramCo, 2007). There, computer-controlled pivot-irrigation arms sprayed seawater sucked in by three diesel pumps at a rate exceeding 28 m^3/min each unit watering a 50 ha (20.2 acres) circle. It took 6.5 h for the arms to complete one circuit. From these data one easily finds that $q_{w,1} = 0.0093 \cdot 10^{-4} \text{m}^3/(\text{m}^2\text{s})$.

The irrigation installation cost c_{irrig} is, of course, proportional with the irrigated land surface:

$$c_{\mathrm{irrig}} = S_{irrig} c_{\mathrm{irrig},1} \tag{89.19}$$

where $c_{\mathrm{irrig},1}$ is the cost of irrigating a unit surface of cultivated crops. Depending on the crops, $c_{\mathrm{irrig},1}$ ranges from 200 to 2,000 USD/acre (Farm Management, 2007) (one acre equals about 4,048 m^2). Here we accept 750 USD/acre which then yields $c_{\mathrm{irrig},1} = 0.185\,\mathrm{USD/m^2}$. The annual maintenance cost for the irrigation installation, $c_{\mathrm{irrig,maint},1}$ is

$$c_{\mathrm{irrig,main},1} = f_{\mathrm{irrig,maint}} c_{\mathrm{irrig}} \tag{89.20}$$

where $f_{\mathrm{irrig,maint}}$ is a given fraction. Here $f_{\mathrm{irrig,main}} = 0.05$ has been adopted. The yearly maintenance cost $f_{\mathrm{irrig,main}}$ for the time period t of the irrigation installation is:

$$c_{\mathrm{irrig,maint}} = c_{\mathrm{irrig,maint},1}(t/365 \cdot 24 \cdot 3600) \tag{89.21}$$

The cost associated to the irrigation installation, $c_{\mathrm{tot,irrig}}$, after the time period

$$c_{\mathrm{tot,irrig}} = c_{\mathrm{irrig}} + c_{\mathrm{irrig,maint}} \tag{89.22}$$

The economic gain per year from the crops irrigated with seawater, $g_{\mathrm{irrig,year}}$, is given by

$$g_{\mathrm{irrig,year}} = S_{\mathrm{irrig}} g_{\mathrm{irrig},1} \tag{89.23}$$

where $g_{irrig,1}$ is the economic gain per unit surface of cultivated crops, per year. The economic gain after the time period t from the cultivated crops, g_{irrig} is given by

$$g_{irrig} = g_{\mathrm{irrig},1}(t/365 \cdot 24 \cdot 3600) \tag{89.24}$$

During 6 years of field trials in Mexico, *Salicornia bigelovii* produced an average annual crop of 1.7 kg/m^2 of total biomass and 0.2 kg/m^2 of oilseed (Imaz, Gay, Friedmann, & Goldberg, 1998). It is expected that the benefit consists of food products like cooking oil and "sea asparagus", a delicacy that sells in Europe for USD 40/kg. In calculations, we considered as possible sale products: oil (0.75 USD/kg) and sea asparagus (40 USD/kg) but only results for this last (more advantageous economically) product are given here. In the two cases, $g_{\mathrm{irrig},1}$ is evaluated to about 0.15 USD/m^2 and 8 USD/m^2, respectively.

89.6 Ecological, Cultural and Social Consequences

This paper focuses mainly on technical and economical aspects. Ecological, cultural and social consequences of the macroproject (both positive and negative) have not been fully considered. To provide a perspective, a few considerations are presented next.

An important problem is that, with continuous seawater imported from the Indian Ocean, the salinity of Eyre Lake will increase year by year. A rather similar problem occurs in case of closed seas, such as the Caspian Sea. But this large body of water has a rather constant salinity because it fills up by fresh river water. The difference is that in case of Lake Eyre, one has an anthropogenic salinization of an episodic inland body of brackish water (Williams, 2001). The accumulation of salt and its effects on Lake Eyre have to be examined and solutions proposed to diminish the consequences have to be proposed. For example, an artificial evaporative southern gulf of the ESR might be created, playing the same role that Kara-Bogaz Gol does for the Caspian Sea. In this way, the ESR's salinity might be kept within reasonable limits. Also, a solution exists to extract freshwater from the Earth-atmosphere (Bolonkin, 2007). This freshwater might be used to decrease the seawater importation need. But the implementation of these (and other) solutions should be studied in much more detail.

The present macroproject should be underpinned by an inter-basin freshwater transfer macroengineering plan renewal, viz., the diversion of Cooper Creek (Kingsford, Boulton, & Puckridge, 1998; Walker, Puckridge, & Blanch, 1997). Cooper Creek is one of the last "wild" (i.e. unregulated) river systems in Australia and is protected by the "Lake Eyre Basin Agreement." But the valuable and infrequent river runoff may be used to dilute from time to time the Eyre Seawater Reservoir, replacing for time intervals the import of seawater. The potential inflow to Lake Eyre contributed by the Diamantina River must also be dealt with somehow. Given that these, and the other rivers that flow into Lake Eyre, have the potential to fill the lake in times of flood the diversion of these rivers would constitute a macroproject in itself. In addition to the large and irregular flood events that fill the lake, brackish water also covers half of the lake every three years and more than half the lake every ten years (Kingsford & Porter, 1993). All these aspects should be studied in detail and solutions to keep the salinity of ESR at a reasonable level should be proposed.

Lake Eyre is not a heavily brackish lake and the land surrounding the present-day lake is not a barren desert. There are abundant plant and animal species established in this region. Indeed, Lake Eyre is one of Australia's largest ephemeral wetlands and a major breeding ground for water-birds. When Lake Eyre floods it supports great numbers of birds, fish and invertebrates. Kingsford and Porter (1993) estimate more than 100,000 water-birds use the lake while Roshier, Robertson, Kingsford, and Green (2001) allege the Lake Eyre Basin has the highest habitat availability for water-birds in Australia, with interconnected wetlands providing broad pathways to the wetter regions of currently drought-stricken southeastern Australia. Also, unpredictable rainfalls produce regions that support a high diversity and abundance of wildlife (Stafford Smith, & Morton, 1990). This macroproject could, no doubt, disturb the extant Lake Eyre Basin ecosystem. Lake Eyre acts as an ephemeral breeding ground for numerous bird species; covering any part of it with floating material could upset this activity, even if, as proposed, the lid will not come close to the shores. Varying Lake Eyre's salinity, water composition, O_2 content, could have adverse effects too.

Australia is a highly urbanized country and more than 50% of Australians live within 10 km (6.2 mi) of the world ocean (Chen & McAneney, 2006). In southern Australia, South Australia is classified as mostly "remote", "other regional-rural" and "small regional" in terms of human settlement characteristics. Only Adelaide is a "large city" (Rofe & Oakley, 2006). The desert surrounding Lake Eyre is a region of very low population density and with a low future population growth projection (Taylor, 2003); human demographic projections are unlikely to change radically. It is preferable that development occur only after the Eyre Seawater Reservoir is emplaced and indisputably proven to be a benefic solution by computer modeling (Dean, Flowerdew, Lawrence, & Eckermann, 2006). Provision for no or insignificant cultural heritage damage to take place ought to be assured. Also, the capping of Lake Eyre would have consequences on the aesthetics of the landscape which is a tourist attraction. The lake is protected as a National Park.

How groundwater flow beneath Lake Eyre might be changed by ESR's presence should also be studied, even if no important negative effects are expected (Holzbecher, 2005). There is a possibility the topography and soils will endure some landscape contamination during emergencies. Design solutions should be proposed to ensure that the visual impact to be tolerable as the hoses/pipelines/tubes can be camouflaged, that the region's groundwater and surface waters won't be polluted, that air quality may improve (less blowing dust), that noise from enclosed electric pumps won't provide a nuisance to anyone, and that construction wastes will be removed and/or discretely entombed. In addition, further research is necessary on the macro-project's possible effects on flora and fauna, groundwater, water and soil salinity and aesthetic and cultural values. A useful initial reference along this line is Williams (2002).

There are many benefits of the macroproject such as provision of photovoltaic energy, potential human settlement in the region, and increased areas for grazing stock. Also, there would be immeasurable economic gains stemming from the removal of dry land as a source of dust storms (Shao, Leys, McTainsh, & Tews, 2007) – it would be immersed by imported seawater – and locally enhanced rainfall will help curtail/diminish such damaging weather events in the region. All of these should be studied in much more detail.

A full-of-water Lake Eyre may change the surrounding climate around, making it more favorable for human settlements. Such a change has been studied with rather disappointing preliminary conclusions; it remains under public debate (Hope & Neville, 2004).

We have shown that biosaline agriculture in the ESR region might be profitable. However, a much smaller scale experiment closer to the coast (even at the scale of single landholder) might be more appropriate before undertaking an ESR macroproject. Indeed, this experiment would eliminate the costs of both ducted pipelines to the lake and costs of transporting the produce from such a remote region. Also, it is obvious that sea asparagus gains its high price per kilogram from the fact that it is somewhat of a "novelty" product; the mass production of sea asparagus could lower the prices. These aspects should be studied, too.

89.7 Conclusions

The present work proposes a macroengineering project, aimed at stimulating economic activity and human settlement in the Lake Eyre Basin. This territory, belonging to South Australia, often described as picturesque, is semiarid and practically unsettled.

Historically, human settlement in the region was dependent on traditional agriculture as a basis, eventually followed by urbanization and industrial activities. In the past 150 years, a number of proposals were made, but none convinced or demonstrated the possibility of improving local arid conditions of inland central Australia. It may be that the chronic lack of freshwater and salt-ridden soils in the Lake Eyre Basin do not allow for the traditional agriculture economy.

But, during the early 21st century, it may opportune to change this previous paradigm. The all-important quantity in this new macroengineering thinking is energy, instead of rich soils and precipitation. The Lake Eyre Basin is suitable for clean, large scale photovoltaic energy production. Large quantities of seawater can be transported without losses on the ground, using large, cheap tension textile tubes. Saltwater from the Indian Ocean can be pumped for input into Lake Eyre, which can be used as seawater reservoir for biosaline agriculture on its encircling shore. Increasing and stabilizing the level of the lake is of crucial importance in the macroproject. For this, apart from the relatively modest saltwater additional input, evaporation from the lake has to be reduced; the only means to perform this is by liding the lake with a floating, impervious, plastic mat (or, alternatively, with buoyant white hollow plastic balls). The exact composition and desired optical properties (reflectance) of this cap remain to be seen. Suppressing evaporation of the freshwater/brackish water is an important factor designed to raise the level of the lake and has the beneficial consequence of preventing salt concentration. In a first stage, in the period of raising levels, salinity is expected even to decrease.

A crude economic cost estimate is included in this paper. We do believe that all the methods and elements presented in this article work, but using them together may even have a synergic effect. However, further research is necessary to provide a broader perspective on both the benefits and the negative consequences of this specific macroproject. The main lines of future research are briefly described in the section entitled Ecological, Cultural and Social Consequences.

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