SALTON SEA ECOSYSTEM RESTORATION PLAN

Final Technologies and Management Techniques to Limit Exposures to Selenium

April 2005

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FINAL TECHNOLOGIES AND MANAGEMENT TECHNIQUES TO LIMIT EXPOSURES TO SELENIUM

This report summarizes current scientific and engineering aspects of technologies and methods that could be used as a component of the Salton Sea Ecosystem Management Plan to limit or prevent environmental and human exposures to selenium. The report presents information on physical, biological, and chemical methods for treating waters containing selenium. Because several of these technologies involve creation of habitat that would attract wildlife, especially birds, this report also describes various management techniques that could be used on a limited scale in conjunction with the treatment technologies to minimize risks to wildlife from selenium exposures (Appendix A).

TREATMENT TECHNOLOGIES

Existing physical (engineering), biological, and chemical technologies for selenium removal and their applicability for use at the Salton Sea are being evaluated as an important aspect of the Salton Sea Ecosystem Management Plan. This report evaluates known technologies for selenium removal from water, indicates if these technologies are proven effective at high-volume applications, and estimates their costs. Methods for managing selenium in soils and sediments are not addressed in this review. This report relies on the results and findings of previous detailed studies, such as those described in a recent publication by Frankenberger et al. (2004) that presents research findings on various treatment options for selenium removal and disposal from agricultural drainwater in the San Joaquin Valley, California. Other detailed studies of treatment options that are summarized and cited in this report, as well as general information related to the treatment technologies for selenium, can be found in publications by Frankenberger and Benson (1994) and Frankenberger and Engberg (1998).

Important considerations addressed in this review are the availability of existing technologies, the media in which the technology can be used, removal efficiencies and present state of success, disposal of wastes or residues, and estimated costs. Reviews of the current engineering technologies, which are based on information contained in various technical reports, are presented below. Table 1 provides a description of the technology, media containing selenium (drainage water or water in the Salton Sea), efficiency, technology cost, and applicability for use at the Salton Sea. An important consideration for the selenium removal component of the Salton Sea Ecosystem Management Plan is to identify where the treatment system(s) could be installed to achieve the greatest removal efficiencies. The two main treatment targets are: (1) drainage waters entering the Salton Sea, and (2) waters (and possibly also sediments) within the Salton Sea. The determination of the target treatment stream will help narrow the ultimate management plan alternative(s).

All of the technologies would require the installation of a treatment “system”, which refers to the components of most technologies that make the remediation or treatment possible. For example, most options require the movement of water through a treatment module, which could require intake structures, pipeline, discharge and distribution systems, pump stations, etc. In addition, several treatment options could involve a combination of treatment processes, including pretreatment. Some of these components are accounted for in the cost of each treatment technology; however, implementation would likely require unforeseen adjustments and modifications for site-specific conditions that would have cost and efficiency implications.

This review addresses the expected effectiveness of each treatment technology. It should be noted that simple parameters such as total waterborne selenium concentration are not necessarily the most reliable indicators for success of in situ selenium bioremediation technologies with respect to minimizing ecological risks (Frankenberger et al. 2004). This is because reductions of selenium concentrations in waters may not result in proportional decreases in the selenium exposure and toxicity in birds and fish.

TABLE 1
Selenium Removal and Remediation Summary Table

Technologies	Description	Media	Efficiency	Applicability to Salton Sea	Considerations	Costs
Physical (Engineering)						
Reverse Osmosis	Forces water through a membrane against its concentration gradient, separating constituents like selenium out of the water.	Salton Sea water or drainage water	Produces a very good quality treated water product, but requires the disposal of brine waste.	RO has been used in large scale operations such as desalination of seawater for drinking water supplies. (Reclamation 2002)	High energy costs, brine waste disposal.	~$440 - $680 per acre-foot of treated water (with a 74 percent recovery and softening), for influent with salinity concentration of 2,200 - 7,000 mg/L respectively. (Reclamation 2002)
Nanofiltration	Membranes are used to separate different fluids or ions.	RO Waste Stream	Achieved selenium removal up to a 95 percent in drainage waters in the San Joaquin Valley, CA. (Setmire 2002)	Nanofiltration pilot studies at the Salton Sea have proven effective at removing selenium from drainage waters, but the technologies are expensive. (Setmire 2002)	Small molecules and ions, like sodium chloride (NaCl) are allowed to pass through in greater quantity.	~$600 - $1,000 per acre-foot of treated water (includes amortized construction and O&M costs, however, this example is not directly comparable to the reverse osmosis example). (Frankenberger et al 2004)
Evaporation by combination of Evaporative Ponds, Enhanced Evaporative Systems (EES), and Salinity-Gradient Ponds	Use the sun's energy to evaporate water and precipitate out salts, including selenium.	Salton Sea water or drainage water	An EES increases the rate water evaporates but does not change the selenium removal of evaporative ponds since they are still used in the final process to concentrate the selenium until it precipitates. The EES has shown average evaporator efficiency of 67 percent, assuming that the evaporator was running 70 percent of the time (Reclamation 2002). This efficiency means that the volume of water, not selenium, is reduced to approximately one-third of the starting volume.	Salton Sea has a favorable hot and arid climate for evaporation to be successful. However, wildlife exposure and maintenance of the ponds needs further evaluation.	Evaporation results in a net loss of water which may be a concern to the Salton Sea. Enhanced Evaporation Systems mechanically spray water and a scale may form on mechanical parts. Salinity-Gradient Solar Ponds may store a portion of the solar energy that can be used to power other processes like desalination, heating, or electricity generation. (Reclamation 2002)	Evaporation pond treatment in the San Joaquin Valley cost $630 per acre-foot of treated water with 2.8 million/year for O&M. EES for evaporation in the San Joaquin Valley cost was $480 per acre-foot. This cost does not include any costs associated with constructing, operating, or maintaining the evaporation ponds where the EES would be used. (Reclamation 2002)
Biological						
Anaerobic Bacteria Removal	Microbes use selenium as the electron acceptor in their energy gaining processes, the end product of which is a reduced form of selenium.	Salton Sea water or drainage water	Requires construction of holding ponds. Has been shown to remove selenium to below detection limits of 2 µg/L from an influent concentration of selenate above 1,800 µg/L. (Applied Biosciences no date)	This technology is being used in other drainage water treatment applications, but has not been tested for large scale applications at the Salton Sea.	Nutrient addition may be required to optimize bacterial uptake of selenium. Wildlife exposure to reduced forms of selenium needs to be considered and evaluated.	~$200 - $500 per acre-foot of treated water includes capital and O&M costs. (Applied Biosciences no date)
Algal-Bacterial Removal	Adding algae to a treatment pond provides a carbon source for bacteria, which can then grow and continue to use selenium, reducing it to a less bioavailable species.	Salton Sea water or drainage water	A pilot study in the Panoche Drainage District in the San Joaquin Valley has been in operation since 1997. Selenium removal rates from drainage waters ranged from 40-80 percent during a two year study (Reclamation 2002). However, recent research indicates that although an 80 percent removal of soluble selenium occurred, the algal-bacterial treatment leads to increased rates of bioaccumulation of selenium in invertebrates. (Amweg et al. 2003)	Pilot studies by UC Riverside and Kent Sea Tech researchers have shown that it is probable that their Controlled Eutrophication Process (CEP) - which uses algal flocculation to remove selenium - is removing selenium by bioflocculation and settling and/or volatilization from the CEP. (Amrhein 2003, 2004)	Disposal of the spent algae product is required. Disposing of the spent algae would also serve to reduce the risk of bioaccumulation in invertebrates.	~$104 - $272 per acre-foot of treated water for a pilot project at the Panoche Drainage District in the San Joaquin Valley. (Reclamation 2002)
Agroforestry	Strategic planting of crops that recycle drainage water, concentrating the highest selenium and salts at the end of the series.	Drainage water	Selenium removal efficiency will increase if the required salt/selenium tolerant crops can be marketed and profitable and if changes in cropping patterns are embraced by local agriculture sectors.	Would involve some changes in current cropping patterns where used.	Requires large areas of cropland, modification of crop patterns, and implementation of on-farm management. Could result in localized groundwater degradation. (Reclamation 2002)	An “integrated drainage management” agroforestry pilot project in the San Joaquin Valley reported costs of implementation at $150 per acre-foot of drainage water. (Reclamation 2002)

TABLE 1
Selenium Removal and Remediation Summary Table

Technologies	Description	Media	Efficiency	Applicability to Salton Sea	Considerations	Costs
Constructed Wetlands	Constructed wetlands are made and planted with vegetation that has high rates of dimethyl selenide degassing. Flow-through wetlands let selenium-contaminated drainage waters flow through a hay bale which has been planted, promoting root mass growth that harbors selenium-reducing bacteria. As the water passes through the root system, selenium is transformed into the less reactive and unavailable form. (Agrarian Research and Management Company 2004)	Salton Sea water or drainage water	Many have shown volatilization and plant uptake capabilities. In a bench-scale experiment testing four species of aquatic plants - Cattail (*Typha domingensis*), duckweed (*Lemna obscura*), hydrilla (*Hydrilla verticillata*), and swamp lily (*Crinum americanum*) – selenium removal was fairly good to excellent. Influent concentrations were 100 ppm or less, and removal was 65 to 100 percent (Carvalho and Martin 2001). In the San Joaquin Valley, a mass balance study indicates flow-through wetlands are successful in capturing selenium. Fifty-nine percent of the total inflow selenium was retained in the flow-through wetland cell, with selenium outflow of 35 percent, seepage 4 percent, and volatilization 2 percent (Gao et al. 2003). In another field test, flow-through wetlands have reported 80 percent removal rates in the San Joaquin Valley. (Agrarian Research and Management Company 2004)	Concerns for concentrating selenium in potential habitat areas for Salton Sea wildlife. However, upon initial inspection by a biologist, flow-through wetlands at the New River do not seem to be posing a risk to wildlife. (Scheidlinger 2004)	Accounting for actual removal and partitioning in sediments, roots, and vegetation increases difficulty in measuring efficiency. Wildlife exposure to reduced forms of selenium needs to be considered and evaluated.	Approximate cost for a constructed wetland is ~$50 - $330 per acre-foot of treated water. This includes fixed costs of land acquisition, grade, fill, and weir construction to form wetland, establishing plant growth; and variable costs of long term inspection, site supervision, site quality, assurance, and health safety support, sampling and analysis for process control. (Constructed Wetland Technology Web page 2004)
Chemical						
Ferrous Hydroxide	Reduces selenium to elemental form which precipitates out and can be removed from the bottom of the reaction vessel.	Salton Sea water or drainage water	Requires pond or reaction space and removal of precipitate. May require pretreatment to achieve pH 9 necessary for the reaction (Reclamation 2002). In a pilot study using drainage waters from the San Joaquin Valley, 90 percent of selenate was chemically reduced, with a reactor time of 6 hours. (Frankenberger et al. 2004)	This technology is being used in other drainage water treatment applications, but has not been tested for large scale applications at the Salton Sea. Chemical treatment could be useful as a final polishing step following biological treatment. (Frankenberger et al. 2004)	Several water quality constituents can out-compete selenium, counteracting the desired selenium precipitation reaction.	$270 per acre foot of treated water, this estimate includes pretreatment but does not include disposal of precipitate waste. (Reclamation 2002)

Selenium biotransformations and transfer pathways through the food web are not simple functions of total waterborne selenium concentration. Instead, ecological risks from selenium exposures depend on the chemical form, as well as the concentration. Thus, the applicability of each of the selenium removal technologies as an important factor in the Salton Sea Ecosystem Management Plan at the Salton Sea will need to be considered and evaluated in the context of the entire restoration alternative.

Existing Selenium Removal and Remediation Technologies

Existing selenium removal technologies potentially applicable to the Salton Sea Ecosystem Management Plan include the following:

- Physical (Engineering) Treatment:
  - Reverse Osmosis
  - Nanofiltration
  - Evaporation Ponds
  - Enhanced Evaporation Systems
  - Salinity-Gradient Solar Ponds
- Biological Treatment:
  - Anaerobic Bacteria
  - Algal-Bacterial
  - Agroforestry
  - Constructed Wetlands
- Chemical Treatment:
  - Ferrous Hydroxide

These technologies are discussed in detail below.

Considerations for all Selenium Removal Technologies

For any selenium removal technology implemented at the Salton Sea, the following factors should be evaluated:

- *Treatment Stream Media* – Determine the target media (water and/or sediment) containing selenium that will be treated, either within the Salton Sea itself or drainage inflow waters.
- *Water Quality* – Constituents in water will affect the ability of the treatment option to remove selenium. A chemical evaluation of the receiving water quality is an important factor for treatment success.
- *Land Area* – Some treatment options involve large-scale land requirements. Land availability and land ownership issues must be considered.
- *Volume of Water* – The amount of water requiring treatment will limit the applicability of some technologies, and this will be a key determining factor in treatment selection.
- *Bench-scale Trial* – For a given technology, laboratory or bench-scale trials using media from the Salton Sea will be important to test applicability and efficiency for the specific environmental conditions present at the Salton Sea or inflow to the Salton Sea.
- *Pilot Study* – After bench-scale testing for a given technology, implementing a field pilot project would provide information on the effectiveness of the technology for the Salton Sea.
- *Adaptive Management* – The treatment technology may be altered on the basis of observations and performance efficiency to optimize effectiveness for Salton Sea medium.

Physical (Engineering) Treatment

Reverse Osmosis

Reverse osmosis (RO) provides treatment by forcing water through a membrane against the natural flow gradient, resulting in the concentration and removal of constituents such as selenium. This technology can provide a pure product, but it also produces a brine waste that requires disposal. Because the Salton Sea is a high-salinity ecosystem, it may be possible to dispose of this waste on site, but potential adverse effects need to be identified and evaluated.

Effectiveness, Removal Efficiency, and Costs

- RO has been used in large-scale operations such as desalination of seawater for drinking water supplies (U.S. Bureau of Reclamation [Reclamation] 2002).
- RO produces high quality water that can be used as a potable, industrial, or irrigation water supply, or it can be directed into the Salton Sea.
- Depending on the desired quality of treated water, different degrees of pretreatment would be necessary. Pre-treatment would include filtration, pH adjustment, antiscalant addition, lime softening, and sedimentation.
- Disposal of the brine waste, which is usually 5-20 percent of the treated volume, may present an additional cost.
- Potential inefficiencies with any filtration technology are related to clogging/fouling problems. The Salton Sea supports high abundances of barnacles, which can clog filtration equipment and reduce efficiency (Amrhein, Remers personal communication 2004).
- The cost for RO (with 74 percent recovery and softening) has been reported at $440 and $680 per acre-foot; for influent salinity concentrations of 2,200 mg/L and 7,000 mg/L, respectively (Reclamation 2002). The cost for using RO to treat influent waters to the Salton Sea would likely be in the higher end of the possible ranges due to the high salinity concentrations and poor water quality. For comparison, Applied Biosciences (no date) estimated the cost for an RO system to be in the range of $1,140-2,933 per acre-foot (see Appendix B).

Nanofiltration

Nanofiltration is another treatment option that uses membrane filters to separate constituents from source waters. Compared to RO, the nanofiltration process potentially can yield higher water recoveries and requires lower pressure and less pretreatment. These characteristics could make it more cost-efficient than RO when comparing similar treatment applications.

Effectiveness, Removal Efficiency, and Costs

- Nanofiltration pilot studies in the Imperial Valley showed that the technology can be very effective at removing selenium from agricultural drainage waters, but it is expensive (Setmire 2002).
- In the San Joaquin Valley, nanofiltration reduced selenium concentrations in drain waters by up to 95 percent (Setmire 2002).
- Nanofiltration does not completely remove small molecules and ions, such as sodium chloride (NaCl).
- Disposal of the concentrated brine waste is required.

- Selenium experts attending a meeting hosted by the Salton Sea Science Office concluded "Nanofiltration of waters post-desalination as well as combinations of nutrient reduction and selenium treatment appear promising" (Tetra Tech, Inc. 2003). This implies that waters treated by nanofiltration would have undergone pretreatment using RO. Thus, costs would reflect nanofiltration as a treatment option for the RO waste stream, but not drainage or Salton Sea waters themselves.
- Costs for nanofiltration are approximately $600 - $1,000 per acre-foot (Frankenberger et al. 2004) of treated water, including amortized construction and O&M costs; however, these costs are not directly comparable to the RO cost examples mentioned previously.

Evaporation Ponds

Evaporation ponds utilize the sun's energy to evaporate water, thereby concentrating salts and other constituents of concern, like selenium. Once the system reaches saturation and salts have precipitated out, the pond can be closed and the salt wastes can be disposed or buried in place. Evaporation ponds could be used to treat brine wastes from RO and nanofiltration treatment processes. Because evaporation serves as a volume reduction step, use of this technology on inflow water would reduce the volume of water entering the Salton Sea. The resulting net loss of water would have an effect on maintaining the current water surface elevation.

Effectiveness, Removal Efficiency, and Costs

- Evaporation ponds could be efficient at the Salton Sea because of the favorable hot and arid climatic conditions and ample sunlight.
- Potential groundwater contamination and wildlife exposure to high selenium concentrations can be mitigated with synthetic or clay liners and netting. However, as discussed in the Management Techniques section of this report (Appendix A), there are difficulties in netting large ponds to reduce bird exposure, and the durability and maintenance of netting or other deterrent devices would have to be evaluated for the Salton Sea.
- The projected annualized costs for a 1,280-acre evaporation pond facility in the San Joaquin Valley were estimated at $2,823,000, with an associated cost of $630 per acre-foot of water treated (Reclamation 2002).

Enhanced Evaporation Systems

Enhanced Evaporation Systems (EESs) are mechanical devices to enhance evaporation pond systems by increasing the surface area of water available for natural evaporation. Increasing the surface area of water involves outfitting the evaporation pond with a sprayer device that creates droplets which are sprayed through the air (Reclamation 2002). The water evaporates and serves as a volume reduction step while salts remain concentrated in an evaporation pond (Reclamation 2002).

Effectiveness, Removal Efficiency, and Costs

- The benefit of using an EES is that it reduces the area and, therefore the land requirements, of the evaporation pond.
- The residual salts that accumulate in the evaporation ponds require disposal or burial in place (Reclamation 2002).
- Due to the residual salt and spray that drift from the nozzles to the ground, a gradual scale formation occurs on the mechanical parts of the machinery and reductions in flow may result. Thus, final evaporation must occur in the evaporation pond (Reclamation 2002).

- An estimated cost of using EES technology to evaporate drainage water in the San Joaquin Valley was $480 per acre-foot (Reclamation 2002). This estimate did not include any costs associated with constructing, operating, and maintaining the evaporation ponds where EES would be used (Reclamation 2002).
- In 1996 dollars, the construction, annual operation, maintenance, energy, and replacement costs for four modules to be installed at the Salton Sea to pump water into a filtering system and then up to the EES towers were estimated as $186 million and $6 million respectively. For nine modules, those costs were $418.5 million and $13.5 million, respectively (Cagle no date).

Salinity-Gradient Solar Ponds

Similar to evaporation ponds, salinity-gradient ponds store a portion of the solar energy that radiates through the surface of the pond. Energy is generated during the natural course of evaporation occurring at the water surface. The solar energy is converted to heat, stored at the bottom of the pond, and creates additional energy as the heat at the bottom of the pond slowly rises through the salt gradient. The energy extracted from this process is used to power other processes such as desalination, heating, or electricity generation (Reclamation 2002).

Effectiveness, Removal Efficiency, and Costs

- Salinity-gradient solar ponds have been in use since the 1950s, but they have not achieved commercial success because the cost of energy produced is not competitive with other existing energy producers (Reclamation 2002).
- Salts accumulate at the bottom of the ponds and require disposal at the end of the project life (Reclamation 2002).
- For a conceptual salinity-gradient pond in the San Joaquin Valley, costs for a system, including liner and netting for groundwater and wildlife protection, were $6,100 per acre-foot. The annual estimated benefit from generation of energy for desalination was $7,800 per acre-foot (Reclamation 2002). However, as mentioned previously, the durability and maintenance for netting at the Salton Sea would have to be evaluated and added to these costs.

Biological Treatment

Anaerobic Bacterial Removal

Biological treatment systems consist of holding ponds that contain sludge at the bottom of a lagoon which promotes growth of anaerobic bacteria. These bacteria use selenium present in the water stream as an electron acceptor. This process chemically reduces the selenium from selenate to selenite or elemental forms of selenium. However, reduced forms of selenium accumulate in the biological sludge and require removal and disposal. In a biological treatment method, such as the one developed by Applied Biosciences, a water treatment process is engineered and uses a highly controlled biological process for the removal of heavy metals, metalloids, and other inorganic compounds (Applied Biosciences no date). The contaminant removal activities of site-optimized microbial cultures in a bioreactor environment are precisely controlled through a regulated nutrient delivery system. Data from operating plants are presented below.

Effectiveness, Removal Efficiency, and Costs

- Selenium removal using biological processes in reactor systems was conducted by EPOC AG at Murietta Farms (California) (Frankenberger et al. 2004). The treatment process uses an anaerobic reduction reaction to precipitate selenium from drainage water in combination with various reactor designs and different carbon sources and nutrients provided to the microorganisms. This system included an upflow anaerobic sludge blanket reactor followed by a fluidized bed reactor with a total hydraulic retention time on the order of a few hours (Frankenberger et al. 2004). This pilot-scale project demonstrated that the two-stage reactor system was an effective combination process. The pilot-scale project at Murietta Farms reduced concentrations of soluble selenium in drainage water from 300 or 500 µg/L to 30 µg/L.

- Applied Biosciences developed highly efficient, site-optimized microbial cultures for removal and uptake for specific environmental settings. This system is referred to as the ABMet® technology. In bench-scale culture studies, the optimized culture technique obtained sustained removal of selenium to below 2 µg/L (the analytical detection limit) (Applied Biosciences no date).
- The success of the ABMet® application is described in the final report for the U.S. Environmental Protection Agency's (EPA) Mine Waste Technology Program Activity III Project 20 – Selenium Treatment/Removal Alternatives Demonstration Project (MSE Technology Inc. 2001). The objective of this project was to test and evaluate technologies capable of removing selenium from Kennecott Utah Copper Corporation's Garfield Wetlands-Kessler Springs water. This waste stream contained an initial selenium concentration of approximately 2,000 µg/L. The following three technologies were tested: (1) ferrihydrite precipitation with concurrent adsorption of selenium onto the ferrihydrite surface, (2) a catalyzed cementation process, and (3) a biological selenium reduction process. The ABMet® selenium reduction process consistently achieved final concentrations below 50 µg/L, and often below 2 µg/L.
- A pilot study using the Applied Biosciences optimized bacteria culture, based on the technology developed at the Garfield Wetlands-Kessler Springs, was conducted at a South Dakota mine site. In this study, the influent selenium concentration was 14 µg/L. After treatment, selenium concentrations were below 5 µg/L, which was the detection limit used in this demonstration study (Applied Biosciences).
- Construction of holding ponds would require enough space and treatment area for the target influent stream. The volume of inflow and concentration of selenium and other constituents present in the water are important considerations.
- For a biological system at the Salton Sea, treatment would most appropriately be focused on drainage waters from agricultural sumps rather than surface water drains. Sump waters are expected to contain the highest selenium concentrations, thus providing the target treatment stream.
- Similar to evaporation ponds and salinity-gradient solar ponds (discussed above), seleniferous water in holding or treatment ponds could represent a significant exposure risk for wildlife and, therefore, would need to be evaluated and managed.
- There may be additional costs if nutrients are needed for optimal bacteria growth and selenium uptake. Substances like acetate and molasses have been found to be suitable substrates for bacterial growth optimization (Setmire 2002).
- Estimated costs from Applied Biosciences were in the range of about $200 - $500 per acre-foot of treated water, which includes capital and O&M costs (Applied Biosciences no date) (see Appendix B).

The USBR continues to evaluate the cost of this technology since it was selected by the Technical Services Center of the USBR as the preferred method of treatment for selenium removal in agricultural drainage water in the San Joaquin Valley (pers. comm. with Scott Irvine, 2004). In December 2003, the USBR projected costs for implementing a selenium bioreactor treatment system for the San Luis Drainage project in the San Joaquin Valley. The cost estimates were calculated in terms of treatment plant capacity and broken up into equipment and construction costs as shown in Table 2. This cost estimate did not project unit costs which would represent a cost per acre foot of water treated per year; however, it is expected that as treatment plant capacity increases, unit cost will likely decrease. USBR has since reviewed these costs and suggest they are probably overly conservative by about 20 percent (Irvine 2004).

Table 2
Estimated Cost Range for Selenium Bioreactor System Using Applied Biosciences Technology for San Luis Drainage Project in the San Joaquin Valley, California

Selenium Bioreactor Treatment Plant Capacity (AF/Y)	Total Equipment Cost ($)	Total Construction Cost ($)	Total Equipment + Construction Cost ($)
365	$882,670	$3,700,000	$4,582,670
1,000	$1,452,200	$7,400,000	$8,852,200
5,000	$3,671,005	$26,000,000	$29,671,005
15,000	$9,839,550	$72,000,000	$81,839,550

Note: The cost estimates were developed by the USBR for evaluating the cost of implementing the Applied Biosciences treatment technology for the San Luis Drainage project. Table adapted from estimates received from USBR. (Irvine 2004)

In September of 2004, Applied Biosciences developed an estimate for the Salton Sea Authority for the cost of a selenium removal pilot project at the Salton Sea. The Applied Biosciences system would use site-optimized bacteria within a bioreactor system to treat waters. The estimate was for a two-stage pilot scale system with 12 months operation that would treat 4 GPM with a 6 hour retention time (6.45 acre feet/year). The total cost of the pilot scale implementation, equipment, technology, testing, contingency, and site travel was estimated at ~$292,140 (Heiner 2004). Pending successful implementation of the pilot project, estimates for a larger scale system could be developed.

Recent and ongoing research by the USBR is evaluating the forms of selenium that result in the bioreactor selenium removal process using Granular Activated Carbon (GAC) in conjunction with selenium-reducing bacteria tanks. Results from this research are indicating that the biological treatment process may produce organoselenium compounds in the product waters that are more toxic than those in influent. Additionally, the fate of these forms of organoselenium in the environment; and their potential for biological uptake, is unknown. However, organoselenium acts similarly to forms of isologous sulfur compounds which are known to cause extreme toxicity by interfering with protein synthesis. USBR is hoping to conduct follow-on studies that would involve stressing the selenium-reducing bacteria to favor a synthesis pathway that avoids or minimizes the production of organoselenium compounds (Kelly 2004).

Algal – Bacterial Removal

Naturally-occurring, selenium-reducing bacteria in biological treatment systems can be stimulated by adding algae as a carbon source for bacteria. This allows the bacteria to grow and reduce selenate and nitrate into less soluble forms (Reclamation 2002). However, algal-bacterial treatment can increase rates of selenium bioaccumulation in invertebrates (Amweg et al. 2003). As with other treatments, there is a disposal requirement for the spent algal product.

Effectiveness, Removal Efficiency, and Costs

- W.J. Oswald and the Applied Algae Research Group from UC Berkeley conducted pilot tests of an algal-bacterial selenium removal (ABSR) system in Mendota, California. The system achieved reductions in total soluble selenium from an influent concentration of 400 µg/L to an effluent concentration of 10 µg/L (Frankenberger et al. 2004).

- A pilot study in Panoche Drainage District in the San Joaquin Valley has been in operation since 1997. The ABSR system achieved selenium removal rates from drainage waters ranging from 40-80 percent during a 2-year study (Reclamation 2002). Although the ABSR system removed up to 80 percent of the total influent selenium, effluent water contained higher amounts of more bioavailable forms of selenium, which increases the toxicological risk to biota. Removing algal cells from the effluent is one design change for the system that could improve the quality of the final effluent (Amweg et al. 2003).
- Microalgal-bacterial treatment requires creation of treatment ponds that represent possible risks for wildlife exposure concerns (Reclamation 2002).
- Researchers at UC Riverside and Kent SeaTech have been analyzing data from bench-scale and pilot studies of a “controlled eutrophication process” (CEP) at the Salton Sea that uses algal flocculation to remove selenium. The current results indicate that it is probable that selenium is removed by bioflocculation and settling and/or volatilization from the CEP (Amrhein et al. 2003, 2004).
- Cost estimates from the Panoche Drainage District range from $104 to $272 per acre-foot (year 2000 dollars) depending on the size of the treatment ponds and influent flow rate (Reclamation 2002).

Agroforestry

Agroforestry refers to an “integrated drainage management” approach to drainwater volume reduction, which would also serve to reduce selenium inflows to a receiving water body or other treatment or disposal systems. In general, this technique involves planned and managed cropping that re-uses agricultural drainage water in a specific sequence which utilizes the uptake capabilities of salt-tolerant vegetation. Salts, coupled with selenium, are taken up by tolerant plants, concentrated at the end of the crop sequence, and eventually treated. However, a highly saline brine waste would accumulate at the end of the sequence and would require disposal (Reclamation 2002).

Effectiveness, Removal Efficiency, and Costs

- Successful agroforestry requires large areas of crop land, modification of current cropping patterns, and on-farm management, in addition to developing a market for the salt tolerant crops (Setmire 2002).
- A field pilot project in western Colorado entitled “Uncompahgre River Basin Selenium Phytoremediation” is evaluating kenaf (Hibiscus cannabinus), tall fescue (Festuca arundinacea), and birdsfoot trefoil (Lotus corniculatus), as well as three species of hybrid poplar (Populus spp.) trees for their ability to take up selenium from Mancos-derived soil. Chemical analyses and project results were pending at the time of the last report (3/15/04); the completion date of the project grant is December 31, 2004 (Fisher 2004).
- Potentials for introducing selenium into the food chain through accumulation in vegetation and in invertebrates living in the brine pond are an issue associated with this technology (Reclamation 2002).
- Localized groundwater degradation could also occur with this technique (Reclamation 2002).
- An “integrated drainage management” agroforestry pilot project in the San Joaquin Valley reported costs of implementation at $150 per acre-foot of drainage water (Reclamation 2002).

Constructed Wetlands

Constructed wetlands remove selenium by reduction to insoluble forms that are deposited in sediments, accumulation in plant tissues, and volatilization to the atmosphere through biological processes mediated by plants, plant/microbe associations, and microbes alone. It has been widely observed that several vegetation types can take up and volatilize selenium and play an important role in design of selenium removal by wetlands. Dimethyl selenide is taken up and degassed by certain wetland vegetation, thereby reducing the selenium concentration in soils and water. However, the kinetics of the process do not appear to be sufficient to remove large quantities of selenium found in some agricultural drainage water. Field-scale studies of flow-through wetlands are listed and discussed below, along with some design concerns.

Effectiveness, Removal Efficiency, and Costs

Vegetation Types that Take up and Volatize Selenium

- In an experiment testing four species of aquatic plants – cattail (*Typha domingensis*), duckweed (*Lemna obscura*), hydrilla (*Hydrilla verticillata*), and swamp lily (*Crinum americanum*) – selenium removal was fairly good to excellent. Growth medium (water) concentrations of selenium in the form of sodium selenite were 100 ppm (1 ppm = 1,000 µg/L) or less, and removal was 65 to 100 percent (Carvalho and Martin 2001). However, this experiment was bench-scale, and conducted within a laboratory setting using extremely high selenium concentrations. Implications for the applicability to the Salton Sea should be based on pilot-scale projects discussed below.

- Recent research findings show that genetically altered plants have great potential for selenium uptake and volatilization. Indian mustard plants were tested on selenium-contaminated soils from the San Luis Drain in central California. Field tests showed that genetically altered Indian mustard plants were able to absorb 4.3 times more selenium than wild-type plants (Science Daily Online 2005).

Field-scale Studies of Flow-through Wetlands

- A field study in the Tulare Lake Drainage District of San Joaquin Valley was used to determine how selenium was removed by a flow-through wetland system (Gao et al. 2003). A mass balance approach was used to estimate selenium removal in each system component. Several flow-through cells were planted with various combinations of the following plants: sturdy bulrush (*Schoenoplectus robustus*), Baltic rush (*Juncus balticus*), smooth cordgrass (*Spartina alterniflora*), rabbitsfoot grass (*Polypogon monspeliensis*), saltgrass (*Distichlis spicata*), cattail (*Typha latifolia*), tule (*Schoenoplectus acutus*), and widgeon grass (*Ruppia maritima*). Selenium concentrations in the inflow to the wetland cells were 19-22 µg/L, and dominated by selenate. A reduction of 21-55 percent in selenium concentration, along with 48-76 percent removal in the mass of selenium, was achieved. The global mass balance showed that 59 percent of the total inflow selenium was retained within the wetland cells, with selenium outflow of 35 percent, seepage 4 percent, and volatilization of 2 percent. Most of the selenium retained in the wetland cells was in the organic detrital layer and surface sediment. Selenium losses due to volatilization and seepage from the system were an order of magnitude lower than the amounts retained in the organic detrital layer and surface sediment.

- Agrarian Research and Management Company has developed another approach to removing selenium with flow-through wetlands. This technology works by directing the flow of selenium-contaminated drainage waters through a series of straw bales that are placed in a flow-through cell and planted, promoting root mass growth that harbors selenium-reducing bacteria. As the water passes through the root system, selenium is transformed into the less reactive and unavailable form. At the Broadview Water District in Firebaugh, California, flow-through wetlands removed 80 percent of the selenium from treated drain water (Agrarian Research and Management Company 2004). Selenium removal has been correlated with two factors. One factor is the amount of straw, which provides a carbon source for selenium-reducing bacteria. The second factor is the residence time of water passing through the wetlands system. Netting must be installed to prevent wildlife exposure and system fouling. Further research is needed in regard to straw disposal and complete volatilization of remaining active fractions of selenium in the straw (Agrarian Research and Management Company

2001). Flow-through wetlands could be a viable option for the Salton Sea because of the availability of space. In addition, initial inspections by USFWS Biologist Joe Skorupa of constructed flow-through wetlands near the New River did not indicate any signs of detrimental effects to surrounding wildlife (Scheidlinger 2004).

Flow-through Wetlands for Selenium Removal: Design, Monitoring, and Wildlife Exposure Concerns

- Flow-through wetlands alone may not result in optimal selenium removal. For example, to increase the 2 percent volatilization that was determined by a global mass balance in the Gao et al. (2003) study, a flow-through system may require additional features and management, such as the addition of a carbon source to increase volatilization of selenium.
- The efficiency of wetland treatment systems decreases if temperatures fall below 15°C (Tanji 2004). Temperatures at the Salton Sea are not expected to inhibit the flow-through system, due to the characteristic hot and arid climate.
- Extensive monitoring studies have been conducted for constructed wetland systems (See Chow et al. 2004, Gao et al. 2003), but the amount of sampling and monitoring involved in performing a mass balance assessment is too extensive for most projects.
- Measuring the volatilization efficiency of constructed wetlands systems is difficult because it involves enclosing the entire wetland or representative area and measuring the evolved gas concentrations.
- Wildlife exposure to selenium concentrations in the New River wetlands are a concern to USFWS biologists. This concern arises from selenium concentrations in bird eggs that were three times the background level, although not toxic. In addition, sediment and water samples indicated elevated levels of selenium within the system. USFWS conclusions about the wildlife exposure to selenium concentrations in the New River wetlands are currently limited by the extent of monitoring and sampling for the project (Roberts 2005).
- In an area like the Salton Sea, the high amount of wildlife using the wetland would be exposed to, and ingest, vegetation or aquatic organisms that contain higher concentrations of selenium.
- One technique to reduce wildlife exposure would be to design and construct alternative (mitigation) habitat without exposure hazards nearby that is more attractive than the constructed wetland habitat with hazards. This concept has been used for evaporation basins in the San Joaquin Valley (Gordus 1999), but would need to be designed for site-specific wetlands, as well as other treatment options.

The low end of the estimated cost for a constructed wetland is approximately $50 - $80 per acre-foot of treated water. Fixed cost items included in this cost are land acquisition, grade, fill, and weir construction to form wetlands and establishing wetland plant growth. Variable costs include long term inspection, site supervision, site quality assurance and health and safety support, and sampling and analysis for process control (Constructed Wetland Technology Web page 2004). For comparison, Applied Biosciences estimated that the costs of constructed wetlands are an order of magnitude higher (~$652 per acre foot) (see Appendix B).

Controlled Eutrophication Process (CEP) for Selenium Removal

- Overall approach of this method is to stimulate rapid growth of algae in a well-mixed high-rate algal pond. The pond design allows for accurate control of mixing rates, algal cell age, and nutrient concentrations. Nutrients are assimilated by the algae, which are then removed from the ponds using gravity settling and consumption by managed populations of filter-feeding fish species, such as tilapia.

- A pilot-scale study was completed using existing facilities in Mecca, CA adjacent to the Whitewater River (Kent SeaTech, 2003). The pilot study was focused only on nitrogen and phosphorous removal, with estimated maximum overall removal efficiency of 77 percent. Even higher CEP removal efficiencies would be expected using site-specific design specifications.

- The use of the CEP method for selenium removal has not been evaluated, so estimates of selenium removal efficiency are not available. A grant to study selenium removal efficiency by this method has been submitted to the State Water Resources Control Board, and that information may become available at a later date.

Capital and operating costs were estimated for demonstration-scale applications under two Options: Option A for Alamo River flows requiring 10 acres for 2 CEP units over 2.5 years; and Option B for Whitewater River flows requiring 5 acres for 1 CEP unit over 2 years. The total direct costs plus overhead were estimated to be $2,726,643 for Option A and $1,238,916 for Option B (Kent SeaTech 2003). The estimates given above were based on an estimated flow rate of 2,000 gallons per minute (gpm) for the Alamo River and 500 gpm for the Whitewater River.

Full-scale implementation of the CEP technology for removing 80-90 percent of the eutrophying nutrient inputs to the Salton Sea is projected to require approximately 4,000 acres of land. (However, land requirements for selenium removal are not known.) In addition to filter-feeding biomass, the system would produce several valuable by-products, including marketable fish, a concentrated algal sludge that could be used as a feed additive and as agricultural fertilizer, and energy from the on-site digestion of algae and production of methane.

Chemical Treatment

Ferrous Hydroxide

Ferrous hydroxide is a chemical method to remove selenium from water by reducing selenium to an elemental form that settles out of the solution. This treatment method is set up in a lagoon pond system. Ferrous hydroxide is added to the water, and the precipitate subsequently is removed from the holding pond and disposed.

Effectiveness, Removal Efficiency, and Costs

- In a pilot study at Murietta Farms in Mendota, California, additions of ferrous hydroxides to drainage waters from the San Joaquin Valley achieved a 90 percent reduction in selenate concentrations. However, the high reduction rate required a reaction time of 6 hours. The cost of this treatment option was estimated at about $148 per acre-foot of water treated (Frankenberger et al. 2004).

- Chemical treatment could be most beneficial and cost-effective as a final polishing step following other microbial treatments (Frankenberger et al. 2004).

- Chemical removal of selenium occurs by means of an oxidation-reduction reaction followed by co-precipitation. The reaction is pH-dependent, and requires the addition of lime to pond water to reach a pH of 9 (Reclamation 2002).

- Several water quality parameters can out-compete selenium, and hence must be removed first. Some of these competing agents are dissolved oxygen, nitrate, and bicarbonate. If these constituents are present in the treatment waters, pretreatment may be necessary to ensure that the desired selenium precipitation reaction occurs (Reclamation 2002).

- The non-hazardous precipitate requires disposal, and the resultant product water also must be disposed or re-used (Reclamation 2002).
- The cost of selenium removal using chemical treatment is estimated at $270 per acre-foot of drainage water treated (year 2001 dollars), but this estimate does not include disposal costs (Reclamation 2002). Applied Biosciences estimated costs of $4,236 per acre-foot for this technology. This estimate is an order of magnitude higher than other estimates, but it includes capital, reagent, O&M, waste handling, and disposal (see Appendix II).

SUMMARY

The information presented in the previous sections of this report demonstrates the availability of several options for treating different water streams containing selenium. Each treatment option, or combinations of treatment technologies, offers different advantages and disadvantages, with a wide range of construction, operation, and maintenance costs. Ideally, any treatment technology or combination of technologies selected as part of the Salton Sea Ecosystem Management Plan would be tested initially as a pilot scale project prior to implementing a full-scale facility.

Lessons learned from selenium treatment projects at other settings can serve to guide initial planning and implementation efforts at the Salton Sea. For example, similar selenium remediation projects in the San Joaquin Valley in Central California have indicated very promising results. Although the two areas differ in several ways, the management principles are transferable to some extent. For example, the success of the Applied Biosciences ABMet® technology in the San Joaquin Valley has spurred interest by the Salton Sea Authority to consider installing a pilot project using the ABMet® technology for farm drainage inflows. However, assessments of the suitability of these technologies for the Salton Sea ecosystem management program also require identifying key differences between the Salton Sea and San Joaquin Valley as an important step. In particular, the San Joaquin Valley does not have issues with shoreline stabilization and shallow water habitats that can be affected by reductions in drainage inflows for selenium treatment. Because these issues are important at the Salton Sea, reducing inflows may not be a viable option for selenium removal.

TREATMENT TECHNOLOGY REFERENCES

Many of the references used for this report are technical reports that summarized existing selenium removal and remediation technologies and contain references that provide more detailed information about each technology. For example, the Frankenberger et al. (2004) publication followed the Task 2 Drainage Water Treatment Final Report (February 1999) by the Technical Committee on Drainage Water Treatment conducted for the San Joaquin Valley Drainage Implementation Program and the University of California Salinity/Drainage Program. Each of these references listed below contains detailed information that may be useful when considering the applicability of a given treatment technology for the Salton Sea.

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APPENDIX A

Bird Management Techniques

APPENDIX A

BIRD MANAGEMENT TECHNIQUES

Some of the treatment technologies discussed in this report would create habitat that could attract wildlife, especially waterfowl and shorebirds that subsequently could increase risks of selenium exposures. For example, species such as the American avocet (*Recurvirostra americana*), ruddy duck (*Oxyura jamaicensis*), great blue heron (*Ardea herodias*), and American white pelican (*Pelecanus erythrorhynchos*), are naturally attracted to the Salton Sea where wetlands along the shore and open water habitats provide many feeding opportunities. A number of management techniques are available to mitigate these exposure risks. These wildlife management techniques may be applicable on a limited spatial and/temporal scale as a secondary component of the overall Salton Sea Ecosystem Management Plan. Similar to the treatment technologies, all of the currently-available wildlife management techniques offer advantages and disadvantages over a wide cost range.

Although many kinds of deterrent devices that may be used to reduce bird exposure to selenium are commercially available (e.g., automatic exploders and pop-up scarecrows), most of them are not effective for large waterbodies. Deterrents such as complete enclosures may be cost-effective for smaller waterbodies but not for larger ones. Additionally, some deterrent methods such as broadcast distress calls and overhead wires may be effective against some species but not others. Therefore, a variety of techniques may be needed for deterring mixed-species aggregations (DWR 1991). The preferred deterrent to reduce bird exposures to selenium should be cost-effective, efficient, and applicable.

A study was conducted in the San Joaquin Valley to determine the efficacy and costs of existing bird-hazing programs used at various evaporation ponds (Salmon et al. 1991). The most effective and appropriate hazing method or combination of methods was found to vary, and the cost-effectiveness also depended on how the hazing was implemented. Availability of alternative habitat for the birds to move to also is an important factor in the success of hazing. A literature review of the various hazing methods and approaches potentially useful in pond operation was completed as a part of the project, and a manual summarizing the findings was developed (Marsh et al. 1991).

This review provides a summary of the various deterrent methods, which can be categorized generally into auditory, visual, physical exclusion, and habitat modification approaches. Most information on bird deterrents exists as unpublished reports and commercial marketing material. Only limited scientific information is available on the efficacy of the various products and techniques and on how they can be best deployed, both to maximize effectiveness and to minimize nuisance to the public. Even less information is available for costs of implementing these deterrents.

The primary question is, do the techniques reduce the levels of bird use below that expected if they are not used? Secondly, is the level of bird use sufficient to offset the cost of using the techniques? And thirdly, do any deterrent categories or specific devices/techniques perform consistently more effectively than others?

The purpose of this review is to address the potential management techniques to reduce bird exposure to selenium at the Salton Sea without interfering with an overall goal for the Ecosystem Management Plan of long-term sustainability of wildlife populations. The main objectives of the review are to:

- gather and review information on past and present deterrent devices and methods used to control birds;
- assess the advantages, disadvantages, and costs (when possible) for the use of deterrents; and
- identify deterrents that may be applicable for use at the Salton Sea.

Deterrent Devices and Methods of Control

Automatic Exploders

Advantages and Methods of Use

Automatic exploders are small “cannon-like” devices that run on propane or acetylene. The devices emit a loud, explosive blast that can be adjusted to explode at different time intervals. They are also mobile, and one cannon may be used to cover an area of about 3-5 acres, if combined with other deterrent devices.

Automatic exploders may be useful as a temporary control measure for scaring away migrant birds but they are typically not effective as a long-term deterrent. Using a combination of automatic exploders along with other deterrent devices (e.g., netting) may be more effective. Birds become accustomed to the devices, so changing methods more often may be required. Typically, exploders are moved every 2-3 days to a different location on the site. Exploding devices that have a timer and a rotary mount that changes the interval and the area where the sound is directed are available and can be more effective.

Disadvantages

The use of automatic exploders requires the devices to be used along with other control methods (e.g., netting). Most automatic exploders are effective only temporarily in scaring away birds. Birds may be frightened away from only the immediate area where the exploder is located. Birds may become accustomed to the noise, especially if short time intervals between explosions are used.

Cost

Initial cost of propane exploders ranges from about $250 to $500/cannon. Therefore, the approximate cost is $85 to $170/acre. Ongoing costs include propane and maintenance for the cannons.

Lights

Advantages and Methods of Use

Strobe lights (similar to those on aircraft), revolving light units, and amber barricade lights are useful, especially for deterring night-feeding birds such as herons (Nomsen 1989). The light produces a blinding effect that causes the birds to become confused and restricts the birds’ ability to forage. Covering unprotected areas using reflective tape, along with increasing the number of lights may increase the effectiveness of the lights.

Disadvantages

Birds may become accustomed to lights quickly and using other deterrent methods along with lights may be necessary to increase the effectiveness. Nighttime use of waterbodies and the effectiveness of lights on nocturnal species using the waterbodies are not known.

Cost

Coverage area is unknown and will likely vary depending on shoreline and vegetation. Assuming 1-acre coverage per light, approximate initial cost would be $335 to $355/acre. Additional costs include power sources for lights and monthly cost of power, maintenance of lights, and power.

Alarm/Distress Calls

Advantages and Methods of Use

Distress calls have been used successfully for discouraging migratory birds from farms in rural and urban situations (Booth 1983, Busnell and Giban 1968). Studies have shown that this method can be particularly effective for deterring certain species of birds (e.g., gulls and night-herons) for many months.

Taped recordings of alarm/distress calls of birds are broadcast over the area in order to repel or frighten other predatory birds (Busnell and Giban 1968). When using a stationary unit, louder volume achieved better results and mobile broadcasting units can be more effective than stationary ones (Booth 1983).

Disadvantages

The alarm distress calls must be re-enforced with other deterrent methods (Busnell and Giban 1968). The calls may loose their effectiveness over time because the reaction to a call varies with the location, species of bird, the size of the waterbody, and the time of year. Other sounds produced electronically (human voice, automobile noise, etc.) are not as effective as alarm/distress calls of birds (Booth 1983).

Cost

Alarm/distress call broadcasters’ coverage will vary with topography, vegetation, number of speakers, type of unit purchased, and maximum volume. Assuming that each unit will cover at least one acre, the estimated cost is $850 to $11,000/acre.

Pyrotechnic Dispersal Devices

Noise Bombs, Whistlers, and Rockets

Advantages and Methods of Use

The pyrotechnic dispersal devices (PDDs) include noise, racket and whistle bombs, bird screamer siren, bird banger, and noise rockets. Rope-firecrackers are another type of PDD (discussed separately) that may be useful for harassment of birds.

Some PDDs use 12-gauge exploding shells from single-barrel, open-bore shotguns (Booth 1983). The range of the exploding shells is about 50-100 yards. Other PDDs fired from 15-mm or 17-mm pistols have shorter ranges (35-75 yards) than 12-gauge shotguns. Most PDDs are commercially and readily available. The use of PDDs requires a permit from government agencies for the discharge of firearms. These devices can be effective when used with other methods such as all-terrain vehicles (ATVs) or boats.

Disadvantages

The use of PDDs requires a high level of effort. Continuous cleaning and checking of the barrel after each round fired is necessary to insure that corrosion and/or obstructions do not remain (Booth 1983). There is also the possibility of injury to personnel if the necessary safety procedures are not carried out properly.

Pyrotechnic devices have proven to be ineffective for control of cormorants. Godin (1986) indicated that whistle and racket bombs could be ineffective for scaring birds if the bombs were used frequently.

Cost

Most of these types of pyrotechnic devices cost from $35 to $60/100. Launchers cost $30 to $60/unit.

Rope-firecrackers

Advantages and Methods of Use

Rope-firecrackers, also known as fuse-rope salutes or agricultural explosive devices, are inexpensive, commercially available, and require little manpower (Booth 1983). Fuses of the firecrackers are inserted through a 5/16- or 3/8-inch cotton rope. As the rope burns, the fuses ignite causing a series of loud explosions.

Disadvantages

Other deterrents should be used with rope-firecrackers for scaring birds. Weather conditions (i.e., wind and humidity) can affect the burning speed of the rope. There is also the danger of creating a fire hazard and preventive measures for fires should be in place before using the devices. Creating loud noises around livestock and human habitation close to the site may be cause for concern.

Cost

Rope firecrackers (fuse-rope salutes) cost approximately $150/case (648 units).

Water Spray Devices

Advantages and Methods of Use

Using a “mist-like” spray over ponds where birds feed diffuses direct sunlight thereby reducing the amount of light penetration into the water and decreasing visibility. Because the spray prevents birds from seeing their prey, birds that are attracted to the waterbody for feeding would be discouraged. Other water spray devices include Motion activated sprinklers that come on when birds are detected and startle and wet the birds.

Disadvantages

The water spray devices may not be applicable for deterring wading or diving birds, and there is no available literature to support this use. The mist-like spray was designed mainly to deter gulls and terns from circular fish tanks (Svensson 1976) and may also be suitable for smaller ponds. It is necessary to obtain sufficient water pressure and to operate sprinklers on an on:off cycle to be effective. However, birds may use areas between adjacent sprinklers. This method may not be practical for large waterbodies due to the costs for adequately covering a large area. In addition, electrical power would be necessary to run the system.

Cost

Costs for installing a system were not readily available but would include electricity, water, piping, controls, and spray heads. Individual motion-activated sprinklers coverage was not listed but would vary with conditions and water pressure and cost about $70/unit.

Visual Deterrents

Advantages and Methods of Use

In general, visual deterrent devices are most effective when they have been put out before birds appear (Nomsen 1989). The range of visual deterrent devices includes scarecrows, bird or mammal silhouettes and models (e.g., owls, raptors, foxes), model aircraft, whirling novelties, tethered balloons, and small aircraft such as helicopters and ultra-lights (Booth 1983). Other types of visual deterrents include trained birds of prey, dogs, and hazing with vehicles such as ATVs or boats. ATVs can be driven along shorelines and areas where other vehicles cannot travel, and they allow the operator to move rapidly from area to area. The noise and rapid movement of the ATV frighten birds, and equipping the ATV with an air horn or siren can enhance these frightening stimuli. Boats may also be used in a way similar to ATVs by frightening birds from the water.

Disadvantages

The effectiveness of using scarecrows, streamers, reflective tape, whirlers, and silhouettes to scare birds has not been determined. Most of these devices may work better when they employ movement and are combined with other devices such as exploders. Weather conditions, such as high winds, can affect the usefulness of these devices.

Helicopters, airplanes and radio-controlled aircraft can be somewhat successful in the short term, but they are not effective in the long term. Birds that are frightened from the ponds for a short time typically return after the aircraft has left the site, especially when there are no other ponds or suitable wetland areas for the birds to go to (Bradford et al. 1991). Weather and expense are important considerations in using these methods. Many trips are needed to keep birds off ponds. Manpower, fuel, maintenance, and machinery costs may not make it economically feasible to use this method.

Human activity conducted to cause disturbance from ATVs or boats is not the most effective method for scaring birds. If the birds acquire the habit of landing then it becomes harder to scare them off and they may just flush short distances and land again. The more birds there are, the less they are likely to be affected by human disturbance. This also may not be economically feasible because of the high level of effort necessary and the maintenance of trained dogs or falcons if this method is used.

Cost

Various visual bird scare devices range from $4 for a 300-foot roll of reflective tape to about $95 each for revolving plastic owls. The cost for hazing with aircraft was calculated to be $1,745 per acre-foot annually (Bradford et al. 1991). ATVs and boats cost several thousand dollars for each vehicle, plus fuel, oil, and routine maintenance.

Physical Barriers

Bird Balls

Advantages and Methods of Use

Bird balls are high density polyethylene (HDPE) that used to cover the entire surface of the water, making the pond unattractive to birds. Other wildlife such as foxes and coyotes don’t attempt to walk onto the balls, as the individual balls do not support the animal's weight. The balls also block ultraviolet rays and minimize the growth of algae and weeds, making it a less desirable place for the birds to roost

Bird balls have been used on mining and wastewater ponds and to minimize bird use at both military and commercial airfields

Disadvantages

The initial materials needed would be hundreds of thousands of balls for a large waterbody so the initial installation would be costly. Additionally, high winds can cause the bird balls to accumulate on the downwind side of a waterbody and leave large areas of open water for birds to use.

Cost

Prices for bird balls depend on the size of balls used and prices were not readily available. At least 43,000 balls would be needed to cover an acre so an estimated cost is $8,000/acre.

Complete Enclosures

Advantages and Methods of Use

Complete enclosure using screening mesh and/or netting is considered the most effective way to deter birds on small waterbodies. Most successful enclosures that have been reported are those that covered small fishponds and those that exclude birds from areas of structures such as buildings and bridges. Mining ponds of up to 500 by 1,000 feet have been covered using netting. Turnbuckles and galvanized or stainless steel cable from 1/4 to 1inch may be used for connecting and securing net panels and lacing twine is used for lashing netting to a structure. Secure-fitting top nets with the appropriate mesh size strung as high as possible above the water surface can successfully keep birds from feeding there.

Disadvantages

Complete enclosure may be more expensive than other deterrent methods and could be viewed as a disadvantage at first. There is a high initial material and installation cost to netting. There is also high maintenance cost of replacing netting as it deteriorates. Typical life of the UV-stabilized netting is about 5 years, but the life of the netting may be shorter in the harsh Salton Sea environment (i.e., wind, UV, and heat). Additionally, engineering the support system, material costs, and construction costs of installing netting over large waterbodies may be prohibitively expensive. Netting, which is expensive to maintain, is regularly damaged by storms and fails to camouflage the liquid surface from the air.

However, savings in day-to-day level of effort may offset initial costs, if the method is appropriate for the size of waterbody from which birds are to be excluded. In addition, birds may be entangled or injured in netting over large netted waterbodies when they try to land on the water but do not see the netting due to weather conditions or approaching in the dark.

Cost

Prices for UV-stabilized bird netting vary from $3,920 to $13,070/acre, depending on the type and weight of the netting used. Installation and maintenance will be additional costs.

Partial Enclosures

Advantages and Methods of Use

Partial enclosures are more advantageous to use on large waterbodies, if they are effective for the kinds of birds at the site. Types of partial enclosures include using lines, overhead wires, screening, and netting.
Screening and/or fencing of ponds can provide protection from wading birds. Different methods include using a twine grid at species-appropriate intervals, stretching strands of polypropylene line between posts, and using a chain of white polyethylene floats along the edges of the pond.

Monofilament fishing line stretched over waterbodies and fixed to metal poles can be used to deter various larger species including cormorants, ducks, and gulls. The spacing of overhead wires should correspond with the species habits. Placing netting along the sides of a pond where overhead wires are used provides protection against birds gaining access on the sides.

Disadvantages

Partial enclosure is less expensive and uses fewer materials than complete netting, but this method cannot exclude most fish-eating birds, waterfowl, and shorebirds. Overhead lines may be successful at deterring flocks of birds but may not deter single birds that are able to land or go in between the wires. Installing and maintaining wires on large ponds would require initial expenses of engineering support systems and the associated materials and construction costs. Also, netting would need to be replaced as it deteriorates and lighter overhead monofilament lines would likely need to be inspected and replaced often.

Cost

Prices for UV-stabilized bird netting vary from $3,920 to $13,070/acre, depending on the type and weight of the netting used. Installation and maintenance will be additional costs.

Habitat Modification

Advantages and Methods of Use

Alternative wetland habitat would likely be required to compensate for potential impacts to waterfowl and shorebirds exposed to elevated levels of selenium. It is possible that some of the wading birds, shorebirds, and waterfowl currently using high-selenium Salton Sea areas could use alternative wetlands, and the wetlands could be located near existing waterbodies. Compensation wetland habitat can be designed and operated to successfully support high densities of nesting waterbirds (TCEP 1999, Tanji et al. 2002). Creating or enhancing nearby habitat may be used to attract birds away from, or provide alternative sites for birds hazed from, high-selenium areas. In the future these lands may be managed for recreation, such as hunting or wildlife viewing in a manner similar to current refuges, which could help to defray some costs.

Disadvantages

Finding adequate alternative sites and the costs of acquiring land and creating/enhancing ponds are likely to be quite high and there is no guarantee that birds will use alternative sites that are created. Managing the site may also be labor-intensive and expensive. It is necessary to collect site-specific information on waterborne selenium concentrations, abundance of nesting stilts and avocets or other representative species, and the number of birds per acre to calculate the amount of alternative habitat for stilts, avocets, or other species to use the protocols that have been developed (TCEP 1999). Additionally, other deterrent techniques (e.g., exclusion and propane cannons) would need to be used to make the high-selenium areas as unattractive to birds as possible.

Cost

A number of protocols have been proposed to estimate unavoidable impacts of high selenium and to determine the acreage of uncontaminated compensation wetland needed (TCEP 1999, USBR 2002). The cost, availability, and amount of alternative habitat are unknown. Additional costs may include engineering, construction, restoration, and management of the wetlands.

DISCUSSION

Choosing the proper control method and deterrent device depends upon many factors. The type of deterrent that is used to scare birds often depends upon the species involved. It is best to begin frightening/scaring methods before birds appear at the site. Once the birds start feeding, their habits become difficult to break, and foraging birds attract more birds.

Common deterrent devices such as visuals, water spray, automatic exploders, pyrotechnics, lights, and alarm/distress calls have variable and limited uses. Most of these techniques may provide only short-term effectiveness and a combination of these devices is usually necessary. Success in frightening birds away depends upon the number of devices used, how and where they are administered, and if their use precedes the establishment of the birds' feeding habits.

The most effective available method is a complete enclosure. This is the one method of control that deters all birds from a waterbody. The problems with this method are that it is costly to implement at first and it may be impractical on large waterbodies. Enclosures, especially over larger waterbodies, may initially require expensive engineering and construction of a support system and also require repair and replacement periodically. Replacement of the netting may be necessary every 3 to 5 years as it deteriorates due to exposure to the elements. However, there may be a savings from future purchases of ineffective equipment and the level of effort required after installation.

If complete enclosures are not feasible, the use of partial enclosures with netting may be the next-best choice of deterrent. There are many different kinds of partial enclosures and their effectiveness can depend upon the species being deterred. Partial enclosures do not exclude all birds.

Regardless of the method used to exclude birds from an area, the habitat will be lost to the birds and may require creation and/or management of clean ponds nearby for the birds to move to. Additionally, having alternative ponds where birds are left undisturbed may help in keeping birds from immediately returning after they are hazed from an area. However, if alternative ponds are successful, once they reach their carrying capacity surplus birds would likely begin to return to the originally hazed sites.

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APPENDIX B

Selenium Treatment Cost Estimates
Prepared by Applied Biosciences

APPENDIX B

SELENIUM TREATMENT COST ESTIMATES PREPARED BY APPLIED BIOSCIENCES

Applied Biosciences Corporation prepared a concise cost summary for various treatment technologies in their marketing materials. Their cost summary is provided below to show another bracket of cost estimates. Their prices for treatment include capital, reagent, operation and maintenance, waste handling, and power. However, because these costs are provided in a marketing brochure for their corporation's product, they are provided here instead of in each direct section of this report. Their representative costs shown below for chemical, wetlands, and reverse osmosis, are all one order of magnitude greater than what has been reported in earlier sections of this report. These higher costs reflect the total costs for implementing these treatment technologies because they factor in the capital, reagent, operation and maintenance, waste handling, and power, whereas some of these factors were not included in previous estimates. Also, the information provided Applied Biosciences is useful in showing the potential range of costs that can be expected within each technology and the relative range for all the technologies.

Estimated Cost Range for Se Treatment Technologies by Applied Biosciences

Process	Total Treatment Cost ($/AF)
ABMet® *	$98 - $391
Lime	$326 - $1,629
Filtration	$978 - $2,607
Reverse Osmosis	$1,140 - $2,933
Wetlands	<$652
Ion Exchange	$489 - $978
Chemical Precipitation	$326 - $1,629
Ferrous Hydroxide	$4,236 +

Note: Table adapted from Applied Biosciences "Cost Effective Metals Treatment" marketing sheet (2003). Estimated costs include capital, reagent, operation and maintenance, waste handling, and power. * ABMet® process is a site-specific optimized treatment developed by Applied Biosciences for water treatment.