supplements for human use, and compost and fertilizers for soil amendments. Marketing opportunities are found in selenium-deficient areas, both in California and worldwide. Additionally, the possibility exists of refining and marketing industrial-grade selenium as a corollary to drainage treatment.

Marketing opportunities are found in selenium-deficient areas, both in California and worldwide.

CALFED should encourage and solicit proposals to conduct a market analysis for selenium products, existing and projected demand, current sources of supply, product manufacturing techniques, economic feasibility, regulatory requirements, and new marketing opportunities.

Active Land Management

Active land management includes demonstration trials of alternative crop selection, and modification of irrigation practices and operation of individual farms, with the primary goal of reduction in subsurface drainage and selenium load discharge.

CALFED should encourage the development and use of alternative cropping and irrigation practices that will reduce subsurface drainage volumes as well as selenium discharges.

Upper Watershed Management

In years of high rainfall on the west side of the San Joaquin Valley, large flood flows from the upper watershed extend to the San Joaquin River near Mendota. The flows from the Panoche/Silver Creek watershed contribute a substantial selenium load in the form of sediment and dissolved selenium in the flood waters discharged to area wetlands, agricultural lands, and the San Joaquin River.

The flows from the Panoche/Silver Creek watershed contribute a substantial selenium load in the form of sediment and dissolved selenium in the flood waters discharged to area wetlands, agricultural lands, and the San Joaquin River.

CALFED should address selenium in stormwater runoff from Panoche and Silver Creeks, and provide funding to (1) determine the specific contribution of upper watershed areas to selenium loads in discharged agricultural drainage, (2) identify and evaluate remediation alternatives, and (3) ultimately assist with implementing the selected alternatives for reducing high selenium runoff from upper watershed areas. CALFED also should encourage and facilitate the ongoing effort to develop a Panoche/Silver Creek Coordinated Resource Management Plan.

Tradable Loads

Tradable load programs for selenium, which allow districts to trade independently agreed upon loads within a geographic area, can give participants greater flexibility in meeting selenium load targets.

CALFED should encourage and support the use of a tradable loads program, as well as other economic incentives, such as tiered-water pricing, as a means to

achieve selenium load reductions. CALFED should work with the Grassland Area Farmers to build on the results of their program.

Land Retirement

Land retirement is not a specific objective of the CALFED Water Quality Program. However, it is a tool available to help meet the program's objectives in the San Joaquin Valley, aimed at controlling degradation from selenium, as well as salinity, associated with agricultural drainage. To further expand on this premise, several aspects need to be understood:

Land retirement is not a specific objective of the CALFED Water Quality Program. However, it is a tool available to help meet the program's objectives in the San Joaquin Valley.

1. Land retirement along the west side of the San Joaquin River watershed is included in the CALFED No Action Alternative to reflect actions planned by the federal government under the Central Valley Project Improvement Act (CVPIA). These actions would occur irrespective of the CALFED Program.

2. Several other water quality management tools exist that would be exercised to their fullest extent to correct water quality problems associated with selenium from agricultural drainage in the San Joaquin River watershed. These tools (for example, drainage treatment and phytoremediation) will help to retain current agricultural lands in agricultural production.

3. CALFED would consider implementing a program to retire lands in order to help meet water quality objectives for selenium under a tiered approach:

   (a) Initially, up to 3,000 acres of lands with the greatest concentrations of selenium present in agricultural drainage would be targeted for retirement.

   (b) If, and only if, 3,000 acres are still inadequate to meet program goals, retirement would be expanded up to a total of 37,400 acres of lands with high selenium concentrations.

These values are based on the report of the SJVDP (now the SJVDIP), titled "A Management Plan for Agricultural Subsurface Drainage and Related Problems on the Westside San Joaquin Valley," published in September 1990 (commonly referred to as the "Rainbow Report"). On page 93 of the report, Table 15 shows 37,400 acres of the Grassland subarea with selenium concentrations in the shallow groundwater greater than 200 μg/l. These values were developed for the Rainbow Report to identify lands that could be considered for retirement. The Rainbow Report also determined how much of the identified acreage has the poorest quality soil and determined that about 3,000 acres fit both criteria. The Rainbow Report estimated that retirement of up to 3,000 acres would enable meeting water quality

objectives for selenium. For purposes of CALFED environmental analysis, soil quality is not considered a constraint.

Solving the problem will require owners of affected agricultural lands in production working cooperatively to investigate and implement land and water use practices. The Grassland Bypass Project, an effort by local agricultural interests to manage drainage problems, is an excellent example of the kind of activities in which CALFED could participate. So, too, is the Active Land Management Program of the San Luis-Delta Mendota Water Authority. This project is directed at managing lands to remain in production while minimizing or completely eliminating drainage flows and constituent loads. To the extent that more intensive measures may be required, CALFED plans to work with local interests to investigate options such as compensated rotational fallowing, consistent with good agricultural practice, to reduce selenium problems. Other options include investigating cropping changes and irrigation system alteration. Even with these and other measures, permanent retirement of some lands still may be needed. Properties already under government ownership should receive first priority for retirement, which would lower the economic impacts of land retirement.

Solving the problem will require owners of affected agricultural lands in production working cooperatively to investigate and implement land and water use practices.

CALFED is committed to minimizing the number of acres retired by cooperating in the successful implementation of the other options. In the event that land retirement becomes a necessity, land acquisition will be voluntary and compensated, and will be implemented with due regard to impacts on local communities and economies. Water made available through retirement of lands would remain under the control of the local water management district.

In the event that land retirement becomes a necessity, land acquisition will be voluntary and compensated, and will be implemented with due regard to impacts on local communities and economies.

Information Needed

A question has been raised over the adequacy of concentration-based standards if control activities prove that concentration objectives can be met. The EPA has convened a nine-member panel in a Peer-Consultation Workshop on Selenium Aquatic Toxicity and Bioaccumulation that is investigating the need for differentiating the toxicity of different forms of selenium and developing site-specific objectives for selenium. If that protocol is developed, monitoring will be needed to determine what the appropriate standard would be for the San Joaquin River.

Additional field trials of selenium-accumulating crop and forage species are needed to determine the potential for phytoremediation over successive cropping, under varying physical and chemical soil conditions and agronomic methods. A selenium market analysis is needed to determine the best market opportunity for Grassland area selenium products.

Existing Activities

The Grassland Area Farmers and the San Luis-Delta Mendota Water Authority have submitted a report to the CVRWQCB, titled "Long-Term Drainage Management Plan for the Grassland Drainage Area." This report addresses in detail the measures to be implemented in order to reduce selenium discharges to Mud Slough and the San Joaquin River from agricultural subsurface drainage. The recommendations of the report are similar to those made in this Water Quality Program Plan with a few exceptions.

The Grassland Bypass Project is an example of a successful program that has improved water quality. The Grassland Bypass Project authorizes the discharge of subsurface drainage from a 97,000-acre area within the Grassland Authority to the San Joaquin River. This discharge is governed by a Use Agreement between the Authority and Reclamation and by WDRs that require a reduction in the amount of selenium loads discharged.

The Grassland Bypass Project is an example of a successful program that has improved water quality.

As a result of this project, the amount of salt, boron, and selenium discharged by Authority members within the Grasslands area has been significantly reduced. In the 1999 water year, salinity was reduced by 32%, boron by 14%, and selenium by 48% of the historical levels of similar water-year types. The Grassland Bypass Project may be further developed as an element of the CALFED Water Quality Program.

Drainage Treatment

Research and development of treatment projects for the removal of selenium from agricultural drainage have been ongoing since the mid 1980s. Progress is continuing on several treatment methods, as listed above. Substantial progress is being made in the testing of two pilot treatment projects. The Algal-Bacterial Selenium Removal Facility at UC Berkeley has been operating for 2 years in the Panoche Drainage District near Firebaugh. CALFED recently funded the continuation and development of this project for an additional 3 years. The Flow-Through Wetland Treatment Pilot Project for the bioremediation of selenium in agricultural drainage at UC Berkeley has been in operation for more than 1 year in the Tulare Lake Drainage District.

Research and development of treatment projects for the removal of selenium from agricultural drainage have been ongoing since the mid 1980s.

The Drainage Treatment Technical Committee, working under the auspices of the joint state-federal inter-agency SJVDIP, currently is evaluating the status and progress of treatment methods for the removal of selenium from agricultural drainage, including an economic evaluation. The committee's report was completed in February 1999.

Land Retirement

Reclamation has initiated a voluntary land retirement program under the CVPIA. Applications have been received from interested landowners in the Westlands Water District (WWD). Reclamation currently is evaluating those applications, as well as planning a land retirement demonstration project that will include restoration of wildlife habitat. Presently, no applications for voluntary land retirement under the CVPIA program have been received from growers in the Grassland area. Land retirement may not be a permanent solution to the problem of managing selenium, as land retirement retains the existing selenium in the shallow groundwater, where unforeseen future rises in the water table could bring selenium to the surface or discharge it to regional water bodies. The pilot projects conducted by Reclamation of the Westlands and Tulare/Kern Subareas will yield valuable information of the effectiveness of the program.

Reclamation has initiated a voluntary land retirement program under the CVPIA.

The Land Retirement Technical Committee, working under the auspices of the joint state-federal inter-agency SJVDIP, also is evaluating the previous assumptions regarding the efficacy of land retirement, including the elimination of selenium-containing subsurface drainage from retired lands. The committee is reviewing computer models that were developed and refined since the SJVDIP land retirement recommendation was made in 1990. The models evaluate the potential reduction in drainage volume and selenium load, as well as soil, water, and air quality impacts from projected land retirement. The committee's report was completed in February 1999.

Phytoremediation

Research on the potential for phytoremediation and volatilization of selenium in agricultural and drainage reuse systems is continuing. Past research has shown that crops such as broccoli, cabbage, mustard, cotton, and canola have a substantial ability to extract selenium from soil and water, incorporate selenium into their tissues, and volatilize it to the atmosphere. Other forage and plant species, such as astragulus, birdsfoot trefoil, tall fescue, kenaf, and atriplex (including some natives), have the same or enhanced ability. Some genuses of plants, such as *Astragulus* and *Atriplex*, are called selenium accumulators and can achieve selenium tissue concentrations of from several hundred up to 1,000 ppm.

Research on the potential for phyto-remediation and volatilization of selenium in agri-cultural and drainage reuse systems is continuing.

Other plants are called selenium non-accumulators, including most crop and forage species; nevertheless, many plants can achieve selenium concentrations in tissue of up to about 50 ppm. The advantage in using crop and forage species over selenium accumulators is twofold: (1) the crop and forage species may be harvested and marketed as beneficial human vegetable and livestock feed supplementation or as an organic matter soil amendment and fertilizer for selenium-deficient soils, and (2) the concentration of selenium in accumulator

species could be toxic as forage for animals and other uses unless it is carefully blended with other low-selenium forage.

Both greenhouse and field trials have demonstrated the ability of certain plant species to extract selenium from the soil. Field trials with mustard resulted in the removal of 46% of the total soil selenium in only 3 years. Simulated field trials with tall fescue have demonstrated that leachate selenium concentrations and soil selenate concentrations are reduced with successive harvests. A UC Berkeley research project was conducted to ascertain the degree of selenium accumulation and volatilization from each of the components of the drainage reuse integrated on-farm drainage management (agroforestry) system at Red Rock Ranch near Five Points in Fresno County. The final report was submitted in December 1998.

Phytoremediation has been found to be an inherent feature of evaporation ponds, as at least three resident microphytes actively biotransform and volatilize selenium—which may account for the declining selenium concentration observed in the ponds during the evapoconcentration of salts. Further, a Bay Area company that is a major producer and marketer of brine shrimp as food for aquarium species has found that evaporation ponds are an excellent medium for the production of brine shrimp. The shrimp uptake and biotransform selenium from the drainage water. A minimal standard selenium concentration in brine shrimp is considered a necessity for the aquarium market. Although brine shrimp can be a major food source for waterfowl, frequent shrimp harvesting combined with traditional hazing methods breaks the food chain and prevents selenium ingestion by waterfowl. UC Davis researchers currently are conducting a project designed to determine the ecologic processes ongoing in the Lost Hills Water District evaporation pond. The project would identify the function of brine shrimp growth and harvest in the bioremediation of selenium, and would establish optimum management techniques for salt utilization as well as selenium bioremediation.

A Bay Area company that is a major producer and marketer of brine shrimp as food for aquarium species has found that evaporation ponds are an excellent medium for the production of brine shrimp.

Selenium Marketing

Current investigation of opportunities to produce and market selenium products is limited. Efforts are underway to develop markets for drainage reuse products, such as wood fiber from eucalyptus, forage from saltgrass and other forage crops, and salicornia as a salad vegetable (considered a delicacy in parts of Europe). A market for selenium-containing brine shrimp produced in evaporation ponds already exists.

Efforts are underway to develop markets for drainage reuse products, such as wood fiber from eucalyptus, forage from saltgrass and other forage crops, and salicornia as a salad vegetable (considered a delicacy in parts of Europe).

Active Land Management

Assessment of the efficacy of current source control practices in selenium drainage load reduction under the Grassland Bypass Project is ongoing, as well as evaluation of opportunities for further reduction. In addition, the Panoche Water District has implemented an alternative cropping trial, using sudangrass on three

parcels and using minimal surface irrigation to enhance crop utilization of shallow groundwater. A significant reduction in the volume of drainage generated from one parcel has been observed. Broadview Water District is implementing alternative cropping and minimal irrigation practices on a one-quarter section, and monitoring the quantity and quality of the drainage generated by this parcel in comparison to traditional cropping systems. The alternatively managed parcel will be rotated within a section, which would be similar to retiring a quarter parcel in each section while still maintaining the land under production.

Upper Watershed Management

Planning efforts are underway to control flood flows and selenium discharge from Panoche/Silver Creek through a Coordinated Resources Management Program with participation by Reclamation, Panoche/Silver Creek landowners, the City of Mendota, Silver Creek Drainage District, and others. Possible actions include implementation of erosion control measures and construction of detention dams.

Tradable Loads

The Grassland Area Farmers initiated a tradable selenium loads program within the drainage project area to help meet established monthly selenium load discharge targets. The program provides incentive to individual districts to more fully and quickly implement some of the other listed approaches.

The Grassland Area Farmers initiated a tradable selenium loads program within the drainage project area to help meet established monthly selenium load discharge targets.

8.5.2 Refineries

The following approaches have been identified to potentially reduce the impacts of selenium that is a by-product of the crude oil refining process.

Priority Actions

1. Reduce selenium concentrations in biota to levels below human health advisories. The issuance of health advisories on the consumption of waterfowl from the Suisun Bay area was one of the key driving forces leading to regulatory actions.

2. Reduce selenium concentrations in biota to levels below ecological risk guidelines. Concentrations of selenium in many biota from the Bay-Delta area are at levels above recommended risk guidelines. Evaluating the impacts of selenium on Bay-Delta estuary organisms will provide useful site-specific ecological risk guidelines to fine-tune selenium mass reduction needs.

3. Reduce selenium loads from refineries by 90% by 2001. This goal has been set by the SFBRWQCB with the intent of reducing selenium concentrations in estuary organisms. If goals 1 and 2 above are met before the full 90% selenium reduction has occurred, this goal may be amended accordingly. If those goals are not reached, the SFBRWQCB may need to take additional actions.

Treatment of Waste Streams

Selenium occurs in several different waste streams in the refining process. Due to the different chemistries of each waste stream within a facility and between facilities, different treatment processes are needed to obtain the maximum removal efficiency at reasonable costs. These treatments include ion-exchange treatments, Sorbplus treatment (a formulation of aluminum and magnesium), iron co-precipitation, activated alumina treatments, primary stage treatments at wastewater treatment plants, and aerobic and anaerobic biochemical treatments.

Use of Alternative Crude Oil

As stated earlier, the San Joaquin Valley crude oil, used primarily by Bay Area refineries, contains from 2 to 12 times higher levels of selenium compared to crude oil from other sources. A change to a cleaner crude oil would reduce selenium at the front end of the refining process.

The San Joaquin Valley crude oil, used primarily by Bay Area refineries, contains from 2 to 12 times higher levels of selenium compared to crude oil from other sources. A change to a cleaner crude oil would reduce selenium at the front end of the refining process.

Sour Water Reuse

Water used for desalting in the refining process (sour water) can be recycled and reused. Reuse may reduce the volume of sour water discharged, but concentrations of selenium will be higher and treatment will be necessary.

Wetland Discharge Treatment

As a final end-of-pipe removal process, wastewater may be discharged through a wetland to remove selenium before its final discharge to the Bay. This treatment method needs to be safe for wildlife.

Information Needed

New research of the impacts of selenium in the estuary is needed to provide regulatory agencies with information to refine current actions.

The potential interactions between selenium and mercury need to be evaluated.

Monitoring efforts to document improvement in the estuary from reduced selenium loadings should be continued and refined.

CALFED should work with regulatory agencies on developing incentives for selenium load reduction by the refineries.

Existing Activities

Refineries and regulatory agencies have spent millions of dollars studying the chemistry of selenium in the various wastewater streams and evaluating treatment and control technologies. Bench- and pilot-scale testing has occurred throughout the 1990s, including the evaluation of filtration, selenium reduction, carbon adsorption, acid/filtration, iron co-precipitation, and ion exchange. Removal success ranged from 25 to over 90%. Detailed evaluations and implementation of the most promising technologies, such as iron co-precipitation and ion exchange, continue. These efforts have culminated with issuance of Cease and Desist Orders to the refineries. Construction of full-scale treatment systems have brought the refineries into compliance. The SFBRWQCB, along with dischargers, is monitoring selenium loads from municipal wastewater discharges and urban runoff to determine the significance of these sources.

Refineries and regulatory agencies have spent millions of dollars studying the chemistry of selenium in the various waste-water streams and evaluating treatment and control technol-ogies.

Current environmental research includes the evaluation of selenium sources, levels, and consequences in the Delta, in a study proposed by USGS and selected for funding by CALFED. An evaluation of the impacts of methyl mercury and selenium interactions on clapper rail reproduction is being performed by the USFWS. Ongoing monitoring of trace elements in water, sediment, and bivalves is being conducted through the San Francisco Estuary Regional Monitoring Program (RMP).