CASCADE ALTERNATIVE – KEY DESIGN ISSUES

by

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CONTROL OF SELENIUM

Selenium is an element of concern since it is able to bioaccumulate in the food chain and can cause harm to established and developing ecosystems. Selenium is found in virtually all materials on earth, and the weathering of rocks is the major source of environmental selenium. Most bio-available selenium is the water-soluble form, and concentrations can be amplified by agricultural irrigation and drainage. Selenium traces can enter the food chain via waters and sediments, and the uptake of selenium depends on the concentrations in water and feed. Selenium is present in relatively low concentrations in the inflows to the Sea, and has accumulated in the bottom sediments of the Sea. The highest concentrations of selenium are located in the northern part of the Sea. Therefore the issue of selenium in the sediments and waters of the Salton Sea must be addressed by any proposed alternative to the restoration of the resource. The extent of the selenium problem will be ascertained after extensive borings and the project's design and construction will need to take this into account.

Substantial studies have been carried out on the role of selenium in the eco-system: the ways the element enters the food chain, the impact on wildlife and the pathway to its effects on human health. However, the understanding of the metabolic pathways by which selenium moves through the food chain is still considered incomplete. It is generally agreed that more selenium should not be allowed to enter the food chain (e.g. via invertebrates, fish, birds, etc.) than is the case in the present situation. Constructed wetlands appear to be effective in reducing selenium concentrations in waters and sediments through phytoremediation (storage in plants) or plant volatilization (release of selenium to the atmosphere). However, selenium may accumulate within these wetlands and gradually diminish their viability for wildlife habitat. At the Salton Sea, the Bureau of Reclamation is currently conducting a study of selenium in the sediments, the water column and the surrounding soils that will provide a database to help address the issue.

Since clay minerals have higher selenium retention rates than other materials, selenium in the sediments may be sequestered effectively in the clay minerals as long as they are submerged. Exposing these sediments to subaerial erosion could result in re-mobilization of the selenium.

The Cascade Alternative keeps much of the sediment in the geotubes or covered with water, and will actually mitigate the problem more effectively than the other alternatives. Under this alternative much of the dry area is comprised of the constructed dikes. It is recognized that, during construction of the dikes, selenium may entrain back into the water column due to the earth moving (dredging) works. The amount of entrainment during the works is dependent on the retention capacity of the sediments, expressed in _g/kg/100 yrs, which is also called the leaching coefficient. A lower leaching coefficient leads to lower entrainment rates. Selenium has a generally low leaching coefficient, and retention in the sediments is generally high, reducing the risks for entrainment of sediments back into the water column during project construction. The temporary re-suspension of the sediments during dredging should be more than offset by the permanent sequestration of these selenium selenium-bearing materials in the geotubes.

The borrow materials for the dike construction will preferably be obtained from areas with relatively low selenium concentrations. The flexibility in design also allows the avoidance of selenium-bearing materials for construction, as well as the minimization of exposed surfaces of higher selenium-bearing sediments. To be able to accurately determine the locations of soils with low selenium concentrations, an extensive soil investigation campaign is envisaged during the design phase of the project. To determine the actual leaching coefficient of Selenium related to the Salton Sea soil, leaching tests may be done on soil samples collected during this soil investigation campaign.

It has been suggested that by covering the selenium-bearing sediments with water, the North Lake Alternative is superior. However, this factor is unproven, and the factors described above for the Cascade Alternative mean that based upon current information, the two alternatives should be treated as equivalent in terms of this impact. The South Lake, Shore Lake, and Low Sea alternatives would all have a much greater uncontrolled exposure of selenium-bearing sediments, and therefore would likely pose a greater risk from selenium than the Cascade or North Lake Alternatives.

After construction, the Cascade Alternative will create a lotic (flowing) rather than a lentic (static) ecosystem as the cascades are continuously flushed, controlling selenium concentrations in the cascade waters. According to recent studies, lotic ecosystems have typically low bioaccumulation rates compared to lentic ecosystems. In this respect the Cascade Alternative distinguishes itself from other alternatives like a static north or south lake or a low sea.

HABITAT ENHANCEMENTS

Existing Situation

The Salton Sea is an ephemeral feature of the environment. It is not an old growth forest. Old growth temperate forests, tropical rain forests, deserts, and tundra are examples of ecosystems in equilibrium attained over thousands of years in relatively stable climatic regimes. The Salton Sea, by contrast, has come and gone repeatedly at least since the

Pleistocene and would have continued to come and go, were it not for the damming of the Colorado River. Originally the Gulf of California extended north to the Salton Sea and they were one body of water. As the Colorado River delta built seaward, the Sea was cut off and dried up. Periodically (every few hundred years), the Colorado flooded the delta and refilled the Sea, only to have it dry up again.

Today the Colorado delta is migrating northward due to the loss of Colorado River sediment to maintain it. The Gulf of California is expanding to the north. At the same time, the marine ecosystem in the northern Gulf of California has changed from an estuarine environment to a largely marine environment because fresh water that naturally flowed into the Sea has been diverted upstream for agriculture and residential uses. Altogether, therefore, the entire Salton Sea-Colorado Delta system is one which was naturally variable, but whose variability has been reduced due to human activity on the River and which is currently rather static.

The Salton Sea itself is a hypersaline lake (salinity ≈ 40‰). It supports one native fish, the desert pupfish. Other fish species such as talapia have been introduced but are being lost because of the increasingly hypersaline condition of the Sea. Most of the freshwater flow into the Sea is from agricultural runoff and the inflow of the New River which carries untreated sewage across the international border from Mexicali. This wastewater is treated in a model treatment wetland before it enders the Sea. In the shoreline areas where this freshwater enters the Sea there are large concentrations of shorebirds. The central part of the Sea, however, is largely devoid of life, including human recreational activity.

Enhancements

The project design would serve to enhance habitat values by the control of sea elevation and salinity. In addition, other habitat enhancements could be added to the proposal, including but not limited to the following:

- **Control of Sea Elevation and Salinity** — Maintenance of fish resources would benefit piscivorous birds. The Cascade Alternative conceptual management plan is designed to control the salinity and elevation of the Sea in specific project areas through the use of the dike and lock system. The Cascade Alternative is specifically designed to create a series of waterways with descending saline concentrations from the shoreline to the center of the Sea. This method will result in a range of habitats that can accommodate the vast variety of fish species currently in the Sea. Such measures would preserve healthy aquatic habitat, thereby ensuring a supply of healthy food sources for migratory and shoreline birds.

- **Enhanced Bird Nesting Sites** — In addition to addressing the health and vitality of the fish populations in the Sea, and thereby the avian food source, the Cascade Alternative will also create nesting and roosting islands to benefit bird species, including the Gull-Billed Terns and Black Skimmers. Specific design features could be included to enhance these habitat benefits.

- **Establishment of Wetland and Other Vegetation —** A wetland greenbelt area around the New and Alamo rivers may be incorporated to create a river extension. This extension would prevent the rivers from becoming cut-off from the Sea under reduced water elevation conditions. Creation and maintenance of native tree habitat could benefit wildlife associated with the Tamarisk Scrub. Detailed project design and vegetation planting would increase these benefits.

- **Wildlife Corridors —** Aquatic wildlife corridors will be considered and incorporated into the final design of the Cascade Alternative. Specifically, population connectivity along the rim of the Sea would benefit the endangered desert pupfish. In addition, the Imperial Wildlife Area, managed by the CDFG, and the Sonny Bono Salton Sea NWR, managed by the USFWS lies within the project area. Both refuges provide habitat for a wide diversity of resident and migratory waterfowl. The refuges also provide marsh habitat and offer the highest quality, year-round marsh habitat value in the project area. Efforts will be made to assist in the conservation of this habitat resource, including development of the project to increase wildlife corridors and facilitate movement of species as the shoreline and elevation of the Sea changes.

- **Monitoring of irrigation related habitat availability**. Currently, IID operates and maintains almost 1,500 miles of agricultural drains. These drains typically are unlined, dirt channels. Water flow in the drains is determined by the irrigation practices on fields adjacent to the drains. Drains contain flows during irrigation, and storms may add to flows in the drains. Water in the drains supports the development of mesic (marsh-associated) vegetation and, in some locations, patches of marsh-like habitats. These mesic habitats, in addition to the productive agricultural fields, attract and support wildlife that historically would have been absent or present in low numbers in the native desert habitat. Irrigation drains serve as aquatic habitat for many species. At least 13 species of fish are known to inhabit the surface drains that discharge directly to the Salton Sea. The state and federally endangered desert pupfish is known to inhabit the terminus of irrigation drains that discharge directly into the Salton Sea. The drain habitat is highly dependent on the rate and amount of drainwater from agricultural fields. When the agricultural fields discharging into a drain are not irrigated and there is little surface runoff, the drain water flows are dominated by the highly saline subsurface water. In the upper portions of the drain watershed, the absence of irrigation activity can dry out drains and might negatively impair aquatic habitat.

  Maintenance activities associated with the drains include maintaining the gravity flow of tilewater into the drains, conveyance capacity and efficiency, and structural integrity of the drains. Vegetation is cleared from drains primarily via mechanical means, although controlled burns and/or chemical and biological control methods are sometimes used. Drain maintenance will need to continue and be altered as needed to accommodate new flow patterns. Drains will be cleaned as needed, depending on the extent of sediment and vegetation accumulation.

The Cascade Alternative could include design features to replace lost habitat values resulting from increasing variations, and overall reductions, in the flows within the irrigation drains.

- **Control of Selenium** — As discussed, above, the issue of selenium in the sediments and waters of the Salton Sea must be addressed by any proposed alternative to the restoration of the resource. Selenium in the sediments may be sequestered effectively in the clay minerals as long as they are submerged.

- **Halophyte Field Enhancement** — The halophyte field could be plowed to submerge the salt and salt-tolerant vegetation could be planted. The area could then be periodically flooded to support this vegetation for dust control and habitat purposes.

- **Institutional Controls** — A variety of institutional controls could be implemented to further enhance habitat values and ensure restoration project success. These could include agreements for guaranteed inflows to the sea and conservation easements to ensure continued agricultural uses, with associated economic and habitat benefits.

Eco engineering – Other enhancements to the habitat features of the project will be evaluated as the design of the cascade alternative progresses. In the final design stage of the project attention will be given to eco-engineering of the project, where design of special habitats will be addressed. Key elements in the final design study are the enhancements to the existing habitats, the development of new habitats and the interrelation with recreational activities in the area.

SEISMIC RESILIENCE OF THE CASCADE ALTERNATIVE

Introduction

The Imperial Valley is one of the most seismically active areas of California. Eight earthquakes of magnitude 6.0 or greater shook the area between 1875 and 1979. There is a major seismic event in the Valley about once a decade. In 1979 the Imperial County Services Building was severely damaged. The event caused an estimated $30 million in damages in the area. According to the USGS report on the event, "Instrumental records throughout the region indicate that the occurrence of earthquakes is confined to the upper 8 km of the crust presumably because of the high geothermal gradient in the Salton Trough and the associated plastic behavior of crustal rocks at greater depths…[and that] nearly all of the observed slip in the Imperial Valley is accounted for by earthquakes."

Due to the seismic activity in the area, the proposed dikes will be prone to high earthquake loads, and therefore need to be designed taking into account high safety factors. Therefore, low-head ridges with beach profiles (like those designed in the cascade alternative) are preferred. Deep water impoundments, where large quantities of water are impounded, should not border these ridges, and should be located at a safe distance.

Among the construction alternatives, the design of the Cascade Alternative is seismically preferred. The low-head dikes of the Cascade Alternative will be very broad crested with beach profiles. These ridges could be constructed in such a way that they provide maximum safety in case of an earthquake. As a result, the Cascade Alternative provides a mix of shallow and deep water, without the construction of risky high-head dams. In the event of seismic failure, the relatively small elevation difference between the lakes would mean that flows would be smaller than under the other alternatives, reducing the risks to any recreational or other users of the Sea. In addition, recreational and other uses would be concentrated in the outer lakes, which would become dewatered in the event of a failure, rather than in the dry areas that would be flooded as would be the case in the event of a failure for the North Lake and South Lake alternatives. The seismic failure risks can be further reduced by additional compartmentalization of the centric cascade lakes. This means that in case of failure even lower dewatering volumes would be unleashed. As a result, the risks to people and property would be much less in the event of a seismic failure when implementing the Cascade Alternative.

The North Lake and South Lake Alternatives would both require a relatively high dam head that should be avoided in an area with potentially hazardous seismic conditions. In the event of failure of the impoundment structure, the water behind the barrier would flow into the opposite basin until equilibrium is reached. If recreational users or others are in the vicinity of the basin being inundated they could become flooded by the flow of water emanating from the upstream basin. Thus, while there might be a relatively low risk of failure, the potential harm is high.

In the final design study of the Cascade Alternative (but also for any other alternative), seismic risk scenarios should be addressed, and the consequences in terms of damage carefully studied. Seismic issues will be among the most important subjects of the final design.

Seismic Features of the Cascade Alternative

The geotubes located with the interior of the dikes are a key element of the Cascade Alternative. The geotubes provide the primary structure for the dikes, and will have a beneficial effect on the internal stability of the dikes during seismic events. This is because the geotubes are intended to contain and form the liquefied slurry used in the construction of the dikes. The same characteristics that lead the geotubes to maintain the form and stability of the liquefied construction materials will also serve to contain and stabilize any liquefaction that occurs during a seismic event.

The final shape of the geotube is determined by the liquefied dredge material initially brought into the geotube. Therefore the tube naturally obtains an optimal shape with respect to seismic stability. If the material re-liquefies within the geotube due to earthquake tremors, the tube will not change its shape and the primary retention structure will stay intact. In this respect the height / base width ratio is important. To further increase seismic resilience, reinforcement of the tube can be considered i.e. by constructing cross-bracings of woven fabrics into the geotube or multiple layers of geotubes with a reinforcement layer and/or scour apron under the structure.

If the construction materials are properly selected and supplemented, the potential for liquefaction in the geotubes should be minimal, as discussed below. Specifically, liquefaction within the geotubes should not be a concern if a granular fill material is used.

Vertical acceleration could also affect the geotubes, but to a lesser degree than traditional rigid structures . In fact, because the geotube containment will be a 200/kNm geotextile (GC1000) it will be a reinforced flexible structure,rather than a rigid one.

Susceptibility to Liquefaction of the Salton Sea Subsoil

Liquefaction also needs to be considered for the subsurface materials in the foundations for the dikes. This is a concern for all of the alternatives, but the relatively low-rise design of the Cascade Alternatives means that smaller loads would be placed on the foundational materials as compared to the other alternatives.

Measures to prevent liquefaction of the base soil are available. Measures like soil improvement of the base soil (i.e. replacement of soil, dynamic compaction, vibroflotation or stabilization measures), creating additional drainage capacity or making foundations with reinforced mats are possibilities to reduce susceptibility to liquefaction. Where, how and to what extend these measures are required will be investigated in the final design study. Foundation stability needs to be further investigated in the final design study. A key element in the study will be a detailed soil investigation which addresses the (sub)soil conditions with respect to susceptibility to liquefaction.

A brief analysis is presented here on the liquefaction potential of the Salton Sea subsoils. The analysis is based on soil information from the “Preliminary In-Sea Geotechnical Investigation” report by URS (January 30th, 2004), which includes borings and cone penetration tests (CPT). The objectives of the URS investigation were: (1) to evaluate foundation conditions for earthen embankments and (2) to evaluate the potential of obtaining suitable borrow material from within the Sea for embankment construction. URS used a self-propelled jack-up barge as a drilling platform to conduct 11 boreholes and 17 CPT’s throughout the area of the Salton Sea. Investigations were extended to 30’-150’ below the seafloor.

URS concluded that recent seafloor deposits, soft in consistency, very weak in strength, and very compressible, occurred to 45’ feet below seafloor elevation at the proposed location of the dam. The seafloor deposit was considered to be a significant problem for dam construction and would need to be removed and replaced with more suitable compacted materials. The report indicates that most of the Sea is underlain by these soft seafloor and lacustrine deposits. Moreover URS was unable to identify areas within the sea where more favorable foundation conditions existed. Finally, the URS report states that “extensive liquefaction of granular deposits in Imperial Valley during the 1979 Imperial Valley earthquake is well documented (Youd and Bennet, 1983). Given the highly seismic area, it is likely that Recent granular deposits below the Sea would have a high liquefaction potential.”

URS identified 6 principle stratigraphic layers in the Salton Sea. Most of the materials identified were fine grained and not directly suitable for embankment construction. Some granular alluvials were identified on the western shore of the Sea. An earlier Bureau of Reclamation (1974) study also indicated presence of sandy materials at the southern extreme of the Sea.

Selection of appropriate borrow materials will therefore be a key element of project design. The following analysis focuses on the most likely source of these borrow materials, the alluvial deposits identified by URS that consist “predominantly of coarse-grained materials that comprise silty sand (SM) with an average of 43% fines content.” These alluvial deposits are compared to the lacustrine deposits that are the most likely to be susceptible to liquefaction, and which should generally be avoided as a construction material. The average fines content is however relatively high, as a content of clay particles (<2mm) of more than about 5% can make liquefaction significantly less likely than for clay-free soil [Obermeier, 1996].

The analysis is based on the following CPT’s that were selected from the geologic cross-sections on the presence of Alluvial Deposits: CPT09, CPT10, CPT12, CPT23. A correlation chart between the Cyclic Resistance Ratio (CRR) and the Corrected CPT tip resistance (qcN1) gives a tool to evaluate the liquefaction potential [Robertson and

Wride, 1998]. The parameters of CRR and qcN1 are derived from the URS report. The data from the Salton Sea CPT's have been plotted in the correlation chart, depicted in figure A.

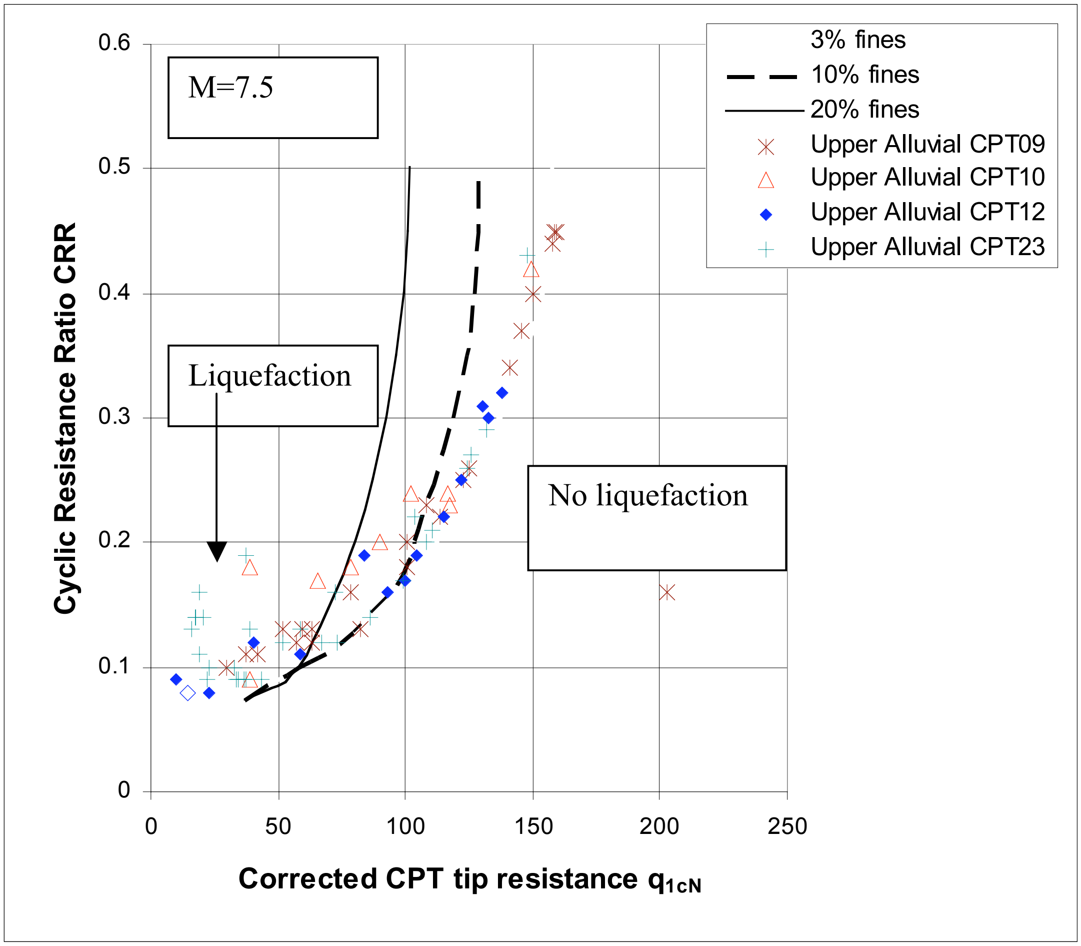

Figure A, CRR – qcN1 relations of the Upper Alluvial Deposits in four CPT's.

Three lines are depicted with 3%, 10% and 20% fines content. Soils with ratios in the areas left of these lines are susceptible to liquefaction; those on the right side are not. The Alluvial Deposits have an average fines-content of about 43%; the distinction line for this fines-content will be even further to the left than the 20% line.

From this brief analysis the following can be concluded:

- The liquefaction potential of the available materials is low to moderate.
- Most of the Alluvial Deposits at the locations of the CPT's 09, 10, 12 and 23 have a low potential for liquefaction, however, the looser deposits with a q1cN < 50 have a high potential for liquefaction.

- The average fines content of the Alluvial Deposits is 43%, so lower values can occur, increasing the potential for liquefaction.

- Calculations have been done for 4 locations. A more detailed analysis is required (and more soil investigation) to generalize these conclusions for the entire Sea.

In summary, suitable materials for the geotube construction do appear to be available in the Salton Sea, but they will need to be carefully selected. It is therefore recommended to conduct a more detailed soil investigation at the construction sites of the dikes and to determine the liquefaction potential for each specific area, as discussed below.

Scope of a Proposed Soil Investigation

Conceptually, the site investigations should be location specific, rather than grid based and the soil investigation should be phased, into 2 – 3 investigations over a period, rather than being combined into a single investigation. This ensures that the information being acquired is relevant and cost effective for the questions being posed by the particular design stage of the project.

In this "initial design and cost" phase it is necessary to review the existing data base and validate or reject the principal conclusions of this data. The spread and quality of the existing data will determine the scope that the investigation should take. A small number of subsurface probes should be carried out in close proximity to the boreholes of earlier investigations. The majority of the subsurface probes should extend the database into areas where the data is scarce or to obtain additional soil parameters.

GOALS OF THE INVESTIGATION

- Provide information about the geotechnical stability of the subsoil

- Provide information on the susceptibility to liquefaction during seismic events

- Provide information about selenium or other chemical concentration levels

- Provide information about suitability and availability of borrow materials (rock and sands)

- Provide information on permeability of the subsoil for groundwater flow investigations

APPROACH AND GENERAL SCOPE

The cascade design has similarities to a corridor project, as structures are concentrated along a particular linear route. The subsoil probes should focus on locations along an initial preferred embankment route, and at initial preferred locations for critical structures such as spillways, bridges and pumping stations. This analysis will involve:

- Purchase of published maps showing surface geology and seismic features (faults and shear zones) along the intended route of the embankments and covering locations of important project structures.

- Along the proposed line of the embankments, carry out rotary boreholes with shell and auger method, sampling with SPTs and Shelby tubes in order to obtain disturbed and undisturbed samples for laboratory testing.

- In a number of boreholes where shearzones are suspected, Packer tests should be carried out to determine the in situ permeability of the soil profile.

The frequency of borehole intervals should be guided by known and existing information. However, initially the spacing should be large (on the order of 350-500m meters). CPTs should be conducted at 75-100m intervals to correlate between boreholes. A percentage of the budget should be held in reserve to the end of the survey program to enable infill drilling with boreholes, CPTs or test pits should occur at locations where geology is more complex, or where specific soil engineering problems are identified.

At the proposed locations of spillways, dams or pumping stations, the program should include detailed soil descriptions from test pits. Seismic refraction surveys should be carried out to identify the top of rock profile, and to search for the presence of subsurface lineations (faults, shear zones) that can affect the stability of foundations or the permeability of the subsoil. Guided by the results from the test pits and the seismic surveys, one or two cored boreholes should be carried out per site to probe the soil / rock interphase.

Additional tasks of the investigation are detailed further below:

Material search for embankment materials

A search for (sand / and workable clay) needs to be undertaken, initially along the embankment route, and if necessary further afield. A potential source of granular materials could be the alluvial outwash fans at the base of nearby mountain ranges.

Quarry search for suitable rock material

Identify potential sources and subsequently the quality of the material. The URS report mentions waste rock piles at nearby mining sites, (these would need to be tested for hardness, grading, sulphide content, density, and weathering).

Laboratory Testing

Foundation materials for embankments testing should include index tests such as grain size analysis, Atterberg limits, determination of moisture content, and bulk density, specific gravity, as well as a number of consolidation (oedometer) tests. In addition the foundation soils should be tested for erodibility (pinhole dispersion testing), and falling head permeability tests. Also chemical analysis on soil samples should be carried out in order to determine the levels of contaminants such as selenium. Additional tests should be carried out identifying the leaching behavior of eventual contaminants

Borrow Materials

Bulk samples should be collected from borrow areas where workable clays and sands have been identified in appropriate quantities. Tests should include compaction testing (modified proctor), shear strength testing of compacted materials (triaxial), falling head permeability testing of compacted clay (cores or blankets), and pinhole erodibility testing.

Final Design and Cost Analysis

When site-specific information becomes available, initially preferred site locations may prove unsuitable or available engineering materials may not meet with project design specifications. This may lead to a review of project design and costs and require a new site investigation aimed to answer specific detailed questions.

Investigate alternative routes and structure locations

Change design parameters to meet more competitive cost criteria or to meet design criteria for seismic hazards.

Water temperature

Water temperature is an important parameter for aquatic habitat development. The total volume of water and depth in an impoundment determines the range of water temperatures. Volume of water can be related to seasonal temperature ranges, while depth can be related to momentary temperature ranges. Generally it can be said that all the restoration alternatives (even with the no option alternative) will lead to lower impoundment volumes, and thus larger seasonal water temperature ranges. In comparison with the other restoration alternatives, the cascade alternative does provide similar momentary water temperature ranges because deep water areas are included within the impoundments. Because of compartmentalization, the various volumes of water are lower than for a one lake alternative. Therefore seasonal water temperature ranges are expected to be larger, but are not considered insurmountable. Expected water temperature ranges and their impact on habitats will be addressed in the final design study.