Table 11. Comparison of Alternative Lake Restoration Methods (Cooke et al., 1993 and other references cited in Table)

Method	Advantages	Disadvantages	Costs (from case studies)	Comments
Dilution and Flushing- addition of low nutrient water and/or high volume water; dilutes P concentration; washes out algal cells.	Can control internal loading, algal biomass (including bluegreens which contribute to internal loading), increase clarity. Relatively low cost if water is available; immediate and proven effectiveness if limiting nutrient decreased. Dramatic improvements in Moses Lake, WA with a 10-20 percent per day water exchange with Columbia River water (EPA, 1988).	To be effective, flushing rate must approach or equal algal growth rate, Principle limitation is availability of low nutrient water. Potential adverse impacts on downstream waters from exported nutrients.	Variable from site to site depending on availability of water and cost of installing and maintaining distribution facilities and outlet structure (Cooke et al; USEPA 1988.)	Level of dilution and flushing under current water rights/operating criteria is inadequate to prevent eutrophication. Unless "new" water can be supplied (e.g. through a well) additional dilution/flushing probably not feasible.
Hypolimnetic Withdrawal -(release of nutrient rich/oxygen poor water from bottom of lake, through siphoning, pumping, or selective release rather than release from surface)	Relatively low capital and operational costs; effective in a large fraction of cases (maximum TP decreased; depth and duration of hypolimnetic anoxia decreased); potential long term and permanent effectiveness in increasing dissolved oxygen, reducing internal P loading.	Effectiveness depends on frequent interchanges of hypolimnetic water (several fold during the stratification period). Three to 5 years of total P export may be necessary to see an improvement in epilimnion quality. Potential adverse impacts on downstream water quality and uses from exported waters (with low DO, high P, and possibly high ammonia, hydrogen sulfide, and metals). Nuisance odor conditions may also occur.	Installation costs, (In 1990 dollars); for a 41 ha lake with 3.4 cubic meters/minute flow, $304,000; for a 287 ha lake with 6.3 cubic meters/minute flow-$45,000. (Indian Creek reservoir has a surface area of about 65 ha.)	Current water rights situation and operating criteria for ICR would not allow substantial releases of anoxic water during the summer when the reservoir is stratified..
Hypolimnetic aeration or oxygenation- Addition of compressed air or pure oxygen to bottom waters of lake during stratification.	Raises oxygen concentration without destratifying the water column or warming the hypolimnion; provides increased habitat and food for cold water fish; can reduce internal loading of P, NH4+, Mn, and Fe.	Effectiveness depends on proper design and sizing in relation to oxygen demand. May increase eddy diffusion of nutrients to epilimnion even if stratification is maintained. Works best for deeper waters (over 12-15 meters). Needs a large hypolimnion to work properly; use in shallow lakes and reservoirs should be viewed with caution (USEPA, 1988).	Dependent on equipment costs, power rates, cost of compressed air. In one case study, initial aeration cost was $6500/ha for 6 months operation ($3.40/kgO2). Another case study had a cost of $2.50 /kg02. Long term costs (mostly operational) considered "relatively modest".	"Aerators" used at ICR did not add oxygen; see artificial circulation below.

Method	Advantages	Disadvantages	Costs (from case studies)	Comments
Artificial circulation (destratification)- injection of compressed air, or mechanical mixing devices	Enlarges habitat for aerobic animals; may reduce internal loading of P and decrease biomass of algae (especially blue-greens). Artificial destratification using bubble plumes reduced internal P loading in Chaffey Reservoir, Australia by about 85%. (Sherman, 1999).	Highly variable results from case to case (USEPA, 1988). Depending on sediment chemistry, may increase internal P loading. Temperature increase in hypolimnion may adversely affect cold water fish. Efficiency depends on air flow rate, depth at which air is released.	\$340-\$460/ha (1990 dollars) for installation and 1 year operation; annual costs \$320/ha (1990 dollars).	"Aerators" used for years at ICR to prevent winter ice formation; apparently did not prevent summer stratification / oxygen depletion.
Phosphorus Removal (Dredging or Drawdown and Scraping)	Rapid, long term decrease in internal nutrient loading and nutrient concentration in water column. Compared to P inactivation, does not introduce a "foreign" substance to the lake.	Must consider disposal site for dredged sediment and prevention of runoff from disposed sediment to surface waters, and sedimentation rate from external sources. Dredging can resuspend nutrients and toxic substances if present in sediment, create temporary odor problems (e.g. hydrogen sulfide), temporarily disrupt recreational uses, have temporary impacts on benthic biota. Drawdown and bulldozing could also temporarily affect recreational and benthic habitat uses and have temporary noise, dust, and traffic impacts.	(Cooke et al 1993) Median costs in 1991 dollars based on 9 case studies: \$ 17,984/ ha. Costs are lower if amortized over years of effectiveness; e.g., Lake Trummen, Sweden had an initial dredging cost of about \$5722/ha; the amortized cost over 25 years was \$229/ha/yr.	ICR probably has relatively low external sediment loading. which can be further reduced through BMPs. ICR sediment is fairly shallow (~6 inches in ___) compared to some lakes which have been dredged for restoration. Cooke et al identify dredging as the most reliable and permanent (although costly) solution to internal P loading if most nutrients are located in the top 0.3-0.5 meter of a sediment core.
Phosphorus Inactivation Using Alum Aluminum salts added to water, and produce a floc which precipitates P in the water column, then settles and provides a barrier to P release from the sediment..	Widely used; many case studies of effectiveness. Rapid, fairly long term (at least 10-15 years) decrease in internal nutrient loading and nutrient concentration in water column; increased transparency, reduced algal biomass. (USEPA 1988). Reduced P release up to 90 percent in laboratory experiments. Can reduce P loading from groundwater seepage as well as from internal recycling (Harper and Harvey, 1999). Sufficient floc may bury resting stages of benthic algal mats and limit future mat formation (Wagner et al, 1999). Apparent low or zero toxicity to aquatic biota with properly buffered applications.	Effects can be negated by high external nutrient loading and/or sedimentation which buries floc layer. If floc layer is too thin, benthic invertebrates can mix it with sediment, reducing effectiveness (Charboneau, 1999). Without adequate buffering (outside pH range of 6-8) , aluminum salts may be toxic . Less effective at removing organic P than inorganic P from water column. Temporary disturbance of recreational uses. Increased transparency may promote macrophyte spread (USEPA 1988).	Median cost of 9 case studies = \$564 ha.(1991 dollars) Cooke *et al.* cite amortized cost of one project which lasted 16 years as \$26.56/ha.	

Method	Advantages	Disadvantages	Costs (from case studies)	Comments
Phosphorus Inactivation Using Iron. Similar effects to those of alum, above.	Less concern about biotic impacts than for alum	Fewer case studies than for alum to evaluate effectiveness, longevity; less guidance on dosage.. Effects can be negated by high external nutrient loading. Would need to use aeration or artificial circulation (complete mixing) to maintain needed redox and pH conditions.		
Phosphorus Inactivation Using Calcium. Similar effect to those of alum, above.	Less concern about biotic impacts than for alum	Fewer case studies than for alum to evaluate effectiveness, longevity; less guidance on dosage. Effects can be negated by high external nutrient loading. May need to maintain alkaline pH to maintain effectiveness; would need aeration or complete mixing on a continual basis. .		
Phosphorus Inactivation using "Riplox" process. (Oxidation of top 10-20 cm of sediment through enhanced denitrification, improves P complexation with iron; prevents sulfate reduction)	Reduced sediment P release up to 90 percent in laboratory experiments; 50-80 percent reductions in lake case studies. Uses chemicals normally found in sediments; chemicals are placed directly in and largely confined to sediments. May last longer than alum treatment.	Fewer case studies than for alum to evaluate effectiveness, longevity; less guidance on dosage. Effects can be negated by high external nutrient loading. Assumes internal P loading due to iron redox reactions; if due rather to temperature and pH may not provide significant reduction. Chemicals must be applied with a special "harrow" device.	\$5200/ha (1990 dollars). (Early case studies used experimental procedures.)	ICR sediment is relatively shallow (~6 inches, within cited 10-20 cm range of effectiveness of method.)

Method	Advantages	Disadvantages	Costs (from case studies)	Comments
Biomanipulation -Food web management (restructuring fish communities) to control algae.		Experimental; many interactions poorly understood, particularly in connection with small europhic lakes. (Such lakes may have significant macrophyte communities) Less precise than mechanical or chemical controls and requires knowledge of food web processes, which can be complex. May have unforeseen ecological consequences. Herbivores encouraged by food web changes may not be able to deal with filamentous bluegreen algae like those present at ICR	Depends on means used to change fish community/control existing fish (drawdown, rotenone, netting, etc.) . Manipulation may be required on a permanent basis in order to make effects last.	Available case studies (mostly eastern U.S. and Europe) do not involve the fish species present in ICR.
Periphyton management- Nutrient rich water to grow attached algae as it flows over a substrate; algae are harvested to remove nutrients from system.	Relatively "low tech"; high nutrient removal efficiency under certain circumstances. (DeBusk et al., undated).	Would require maintenance; presence of structures at ICR could detract from recreational experience; efficiency under conditions at ICR not known; disposal site would be needed for algae/nutrients.		
"Pretreatment"- Use of wetlands,detention basins or upstream reservoirs to remove nutrients in inflow to lakes/reservoirs.	Reduces external loading; wet detention basins provide 47-68% removal of total P. Wetlands- up to 83 % removal of P. Jordanelle Reservoir on Provo River, UT reduced downtream P by about 25% (Miller and Cutler, 1999).	Would not address internal loading at ICR. Wetlands may release P at certain times of year. Treatment facilities could require maintenance such as sediment removal from basin, harvesting of vegetation from wetland.	Depends on size and maintenance requirements.	