RU220

Final Report

Assessment of Current Information on Water Quality and Environmental Status of Cherry Creek Reservoir with Recommendations for Future Programs

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Introduction

Federal and state governments are promoting watershed management as a basis for protection and wise use of water resources. This concept is appealing because the amount and quality of water resources are determined by the sum of activities in an entire watershed.

Despite the advantage that it offers for control and protection of resources, watershed management is presently unusual in the United States because the administrative framework for regulation and protection of resources is typically defined according to boundaries that transect watersheds. In this sense the Cherry Creek Basin Authority, which brings together the common interests of the Cherry Creek Basin, is both unusual and advantageous as a basis for rational management of water resources. It also provides a valuable revenue base for the evaluation and solution of problems.

The Cherry Creek Basin Authority has proven its value in control of sediment transport to Cherry Creek Reservoir and in promoting and supporting aesthetic and physical improvements such as those of Shop Creek. The Authority has also invested heavily in studies of phosphorus transport and of trophic state for Cherry Creek Reservoir. These studies, while clearly important, have been less successful than the sediment control projects because they have not yet led to firm conclusions that can be translated into management options.

The purpose of this report is to provide an overview of the present state of knowledge about Cherry Creek Reservoir and its watershed, to evaluate the adequacy of present study programs to produce information that will be useful in management, and to draw conclusions about the advisability of various management options.

Overview of Cherry Creek Reservoir and Its Tributary Waters

Cherry Creek Reservoir began to accumulate water in 1957 but was not subject to intensive environmental scrutiny until the Clean Lakes Study of 1981-82 (DRCOG 1984). The Clean Lakes Study led to the adoption of site-specific water quality standards for phosphorus in 1984. Although the Corps of Engineers has monitored water quality in the Reservoir since 1975, there is no information on water quality for the first 18 years of the reservoir's history. Therefore, the original status of the reservoir is difficult to reconstruct and cannot be used as a point of reference for the present status of the lake.

Cherry Creek Reservoir has been monitored intensively since 1984 under sponsorship of the Cherry Creek Basin Authority. This monitoring and the earlier Clean Lakes Study should have provided a firm basis for assessment of the current and recent past status of the reservoir. For a variety of reasons to be summarized in this report, the intensive data collection effort has not produced as much reliable information as it might have, and a number of basic but important aspects of water quality in the basin remain unresolved.

The geologic setting, land use patterns, climate, and physical features of the Cherry Creek Basin and of the reservoir have been well described in the Clean Lakes Report (DRCOG 1984) and in a recent review by Knowlton and Jones (1993), and need not be repeated here. However, it is useful to focus attention on a few features of the Cherry Creek Reservoir and its watershed that might be considered somewhat unusual or especially significant to the evaluation of water quality. A summary of these special features is given in Table 1.

Cherry Creek Reservoir has a longer water retention time than most reservoirs. This means that algal populations in the lake are very unlikely to be controlled by physical removal, even during relatively wet intervals, and it also suggests that horizontal uniformity of water quality is likely to be higher than it would be in some reservoirs that have high rates of water replacement.

The watershed of Cherry Creek is very large in relation to the size of the lake. This feature of the watershed, when taken in combination with the absence of surface base flow in Cherry Creek, creates some special difficulties for the evaluation of land use in relation to nutrient transport: land use practices or nutrient sources that are distant from the lake may have less practical importance than those closer to the lake in this situation.

Hydrology presents some special difficulties in the Cherry Creek setting. Much of the water from the upstream portion of the basin is intercepted by pumping from the Cherry Creek alluvium. Even so, substantial amounts of groundwater reach Cherry Creek Reservoir in the form of seepage and discharge from the surface of the alluvium within the wetland area at the upper end of the reservoir. Because of the large wetland at the upper end of the lake, delivery of suspended or dissolved materials from the watershed to the lake is really a 3-part process (watershed to wetland to lake) rather than a 2-part process (watershed to lake), as it would be for many reservoirs. The wetland can intercept or modify dissolved or suspended solids from the watershed, and thus may influence the mass loading of the lake. The wetland may also affect the water budget of the lake.

The volume and mean depth of the lake have been greatly reduced in the past by sedimentation. Although the rate of sedimentation has been greatly reduced by the Cherry Creek Authority, Cherry Creek Reservoir is very shallow by comparison of most reservoirs of smaller size. Shallow reservoirs are less likely to develop severe oxygen depletion than deep ones because they experience sufficient mixing or turbulence to transport oxygen from the upper layers to the lower layers. The presence of oxygen near the bottom of the lake minimizes the return of phosphorus from the sediment surface to the water column, and in this sense is beneficial in controlling of trophic state. On the other hand, a shallow water column may promote the growth of algae, and particularly of nuisance blooms, because it reduces the shading of algal populations that would occur if the lake were deeper. Also, certain types of nuisance bluegreen algae seem to be favored by shallow lakes.

Another important feature of Cherry Creek Reservoir is the prominence of storm loading as a transport mechanism for suspended solids and nutrients. The surface flow of Cherry Creek at the Park boundary occurs entirely in response to storms or unusual periods of wet weather lasting several days. This type of transport regime, when combined with semi-arid conditions and disturbed soils, results in large pulses of suspended solids and associated nutrients. Phosphorus that is associated with the suspended solids under these conditions is subject to especially high sedimentation rates in the reservoir. In contrast, phosphorus that enters along with base flow from seepage in the Cherry Creek channel, and from Shop Creek and Cottonwood Creek, is far less subject to sedimentation after it enters the reservoir. Therefore, an understanding of the relationship between phosphorus concentrations in the reservoir and phosphorus loads reaching the reservoir requires a particularly careful analysis of sedimentation rates.

Analysis of Present Knowledge and Recommendations for Future Study

Hydrology

Analysis of nutrient and sediment sources for Cherry Creek Reservoir is seriously hampered by lack of appropriate hydrologic information. Transport of nutrients and sediments to the lake cannot be managed until a more detailed and more reliable water budget is available for the Cherry Creek basin.

Sources of water below Arapahoe Road need to be quantified. A rough summary is shown in Figure 1, but the numbers need to be worked out with much greater certainty. Flows from Shop Creek are well documented, as are the flows from Cottonwood Creek. The flows from Quincy, although presently undocumented, are probably small enough to be estimated roughly without being measured constantly. The greatest uncertainty in quantifying water sources for the lake is Cherry Creek itself. Surface flow is measured at the Arapahoe Road gage, but this does not take into account removal of water through the extensive wetland area en route to the reservoir. In addition, groundwater movement is undocumented. A study conducted for the Authority by Leonard Rice (1989) shows by means of calculations that as much as 2400 acre-ft of water passes beneath the reservoir in the Cherry Creek alluvium, and that an additional 2000 acre-ft leaves the reservoir and passes through the alluvium under the dam. While the calculations were done by standard methodology (use of Darcy's equation), such calculations leave a wide margin of uncertainty, and should be replaced or supplemented with empirical measurements if at all possible. Most importantly, the study by Leonard Rice indicates that groundwater from the Cherry Creek alluvium does not enter Cherry Creek Reservoir. Field inspection of the upstream end of the reservoir shows that this assertion cannot be correct. There is a base flow of at least a few cfs in the Cherry Creek channel very near the reservoir, as well as extensive seepage along the flats at the upper end of the reservoir. Therefore, groundwater transmission from the uppermost portion of the alluvium to the reservoir is a significant element of the water budget, but is undocumented (1 cfs for a year would be almost 800 acre-ft). Obviously, the source of this water, as well as its amount, will be critical to development of nutrient management strategies for Cherry Creek Reservoir.

The water budget of the upper portion of the basin is also poorly known. Surface flow in Cherry Creek reaching the gage at Arapahoe Road is measured, but surface flow occurs only in very wet weather. Groundwater flow past the Arapahoe gage is of major interest, but is undocumented. If groundwater flow past Arapahoe gage is small relative to the total water inflow to Cherry Creek Reservoir, agricultural practices and other factors in the uppermost part of the basin may be of little concern in relation to lake trophic status. If groundwater flow past this point is high, nutrient management in the upper basin will continue to be a matter of concern.

The sources of water that may reach the Arapahoe gage should be quantified. It is important to know the amounts of basin water that are brought to the upper portion of the watershed (probably for the most part through wells located in Parker), as well as any removal of water from the basin (this appears to be small, but should be documented). In addition, a total removal of water at the Aurora pump stations should be part of the record: pumping of large amounts of water out of the alluvium at the Aurora well sites may actually reduce the concern for nutrient management in the uppermost part of the basin.

Color and Transparency: The Influence of Algae and Inorganic Suspended Solids

The color and transparency of a reservoir are affected by three factors: dissolved organic substances, algae, and nonliving suspended material. Waters that have very low amounts of all three of these components are transparent and have a blue color. Waters of this type are frequently valued because of their aesthetic appeal and their association with high water quality. However, dissolved organic matter, algae, and nonliving suspended material are to be expected in moderate to large quantities in lakes of the Front Range because of the geologic setting, climate, and land-use matrix. For management of water quality, the main question is whether any of these components reach undesirable extremes that lead to a degraded visual appeal for waterbody and, if so, whether control is feasible.

Dissolved organic matter adds a brown color to water. It is primarily derived from soils or decaying terrestrial organic matter and is typically not easily controlled by management practices. Although this component has not been quantified for Cherry Creek Reservoir, it is probably only a moderate influence on the appearance of the water and is of no great concern for management purposes.

Algae impart a green color to water, although different kinds of algae yield varying shades of green extending even to yellowish or brown colors. Algal populations in excess of about 20 µg/l of chlorophyll are generally judged by the public to represent aesthetic degradation of a waterbody. This is perhaps the main reason for concern about algal growth in Cherry Creek Reservoir, although there are other concerns as well (loss of oxygen, welfare of sport fish). Even though there are numerous flaws in the data base, it is clear that Cherry Creek Reservoir supports substantial algal populations and that the reservoir occasionally develops large nuisance blooms of unicellular algae (phytoplankton). It follows that the color and transparency of Cherry Creek Reservoir are in part related to the algal populations.

The third factor contributing to transparency and color is nonliving suspended material, which can be either organic or inorganic (clay or silt). Nonliving suspended material of an organic nature is unlikely to be a major factor in Cherry Creek Reservoir because biodegradation typically minimizes this component in lakes. However, the inorganic fraction is of special interest in Cherry Creek Reservoir because the lake has received very large amounts of fine suspended solids since its construction. An unanswered question is whether or not this inorganic particulate material is held in suspension or is resuspended in sufficient quantities to affect the transparency and appearance of the lake. The present data base provides no answer to this question. For management purposes, it is important to know approximately how much of the transparency and color of Cherry Creek Reservoir are controlled by algae and how much by inorganic suspended solids. A reasonable guess based on current information is that most of the variations in transparency and color are related to algae and not to inorganic suspended solids.

A one-year program of moderate cost would clarify the relative importance of algae and inorganic suspended solids in controlling the appearance of Cherry Creek Reservoir. This program would require, for three stations on the lake, bi-weekly collection of transparency data (by quantum sensor as well as secchi disk) samples for total suspended solids, chlorophyll *a*, particulate organic carbon, and algal biomass composition (cell counts).

Reassessment of the Phosphorus Standard

The phosphorus standard for Cherry Creek Reservoir was established on the basis of information that was available when the standard was set. Since that time, monitoring has indicated phosphorus concentrations consistently above the standard. This has led to suspicions that the phosphorus standard may have been set at too low a level. Unfortunately, firm conclusions are impossible because of flaws in the data set. There has been no quantitative reassessment of the phosphorus standard since it was set.

The phosphorus standard should be reassessed on the basis of phosphorus yield information from selected portions of the watershed. First, the basis or rationale for the standard should be worked out conceptually with the Colorado Department of Health Water Quality Control Division. For example, is the standard intended to represent background conditions for an undeveloped watershed, or is it intended to include agriculture and other potentially unregulated activities that contribute phosphorus to the lake? When these principles have been resolved, the Basin Authority should support a study of the mass yield of phosphorus for watershed segments that represent the basis for the standard and, with due allowance for reduction of phosphorus concentrations in the lake due to sedimentation, should show whether or not the current standard has a rational basis.

Phosphorus Loading of the Reservoir

The phosphorus loading of Cherry Creek Reservoir has not yet been quantified. The reservoir receives a substantial amount of base flow through seepage and through groundwater that surfaces within the wetland area. This water has not been sampled for phosphorus concentration, nor has its quantity been estimated. However, it could easily amount to 2000 acre-ft or more per year. In addition, surface flow in the Cherry Creek drainage is now sampled so far upstream that it does not necessarily represent loading to the reservoir. Because of the presence of the wetland at the upper end of the reservoir, phosphorus that passes the sampling station may not actually reach the lake.

The phosphorus load of Cherry Creek Reservoir should be estimated routinely. This will require a redesign of the sampling program in such a way as to provide reliable estimates of the phosphorus actually crossing from the watershed to the lake.

Analytical Coverage for Phosphorus

Interpretation of phosphorus dynamics in Cherry Creek Reservoir is presently handicapped by insufficient information on fractionation of phosphorus. Analysis should include soluble reactive phosphorus, total soluble phosphorus, and total phosphorus (or particulate phosphorus if the total is to be obtained by summation of the fractions). The analytical limits for all of these fractions need to be sufficiently low that they can quantify most of the ambient concentrations in the lake. In the past, the analytical limits have been too high.

Algae

The only quantitative measure of algal abundance presently available for the Cherry Creek Reservoir is concentration of chlorophyll *a*. This is a standard way of measuring algal abundance. Unfortunately, as shown by Knowlton and Jones (1993), the measurements to date are probably not reliable and therefore offer a weak basis for interpretation or for conclusions about algal abundance and trophic state of Cherry Creek Reservoir.

Handling of samples is particularly critical for chlorophyll. Samples that become overly warm, are exposed to light, or are stored for more than a short time often show a decline in chlorophyll concentrations. In addition, some lakes present special problems in the extraction of chlorophyll prior to measurement. These difficulties need to be worked out in the future because there is little use in collecting information on chlorophyll that is not reliable.

There are other ways of measuring algal abundance, and the past bad experience with chlorophyll suggests that these might be added to the Cherry Creek measurement protocols as insurance against continued problems with chlorophyll measurements. Quantitative counts of algal abundance accompanied by estimates of cell volumes for each species are not particularly expensive and would be a valuable supplement to chlorophyll *a*. In addition, such counts would provide information on compositional changes in phytoplankton. These changes in community composition for phytoplankton are of great importance in the interpretation of nuisance blooms, which typically involve certain species that are notorious for causing water quality problems.

Another possible measure of algal abundance is particulate organic carbon. Although particulate organic carbon measurements actually include both living and nonliving organic material, most of the organic carbon in lakes is typically accounted for by phytoplankton. Therefore, measurements of particulate organic carbon could be used as a supplement or substitute for chlorophyll measurements.

There is no information at present on the vertical distribution of algae in Cherry Creek Reservoir. This is an unfortunate deficiency because some of the water quality problems associated with algae are related in part to changes in the vertical distribution of algal biomass. For example, the formation of nuisance blooms of bluegreen algae is often associated with the occurrence of buoyancy, which brings all of the biomass to points near the surface where it can be seen.

Transparency data indicate that Cherry Creek Reservoir is moderately eutrophic. The chlorophyll information, although unreliable and irregular, seems to support this conclusion. However, concentrations of chlorophyll in the range of 20 µg/l (indicating a moderately eutrophic condition) are probably quite acceptable in the Front Range because the native waters of this area are likely to be at least moderately eutrophic. The main concern for Cherry Creek Reservoir is extreme eutrophication, which would be accompanied by frequent or extended nuisance blooms of bluegreen algae. The effect of this condition is already evident from the brief nuisance blooms that have occurred in the lake. These blooms involve the production of large amounts of chlorophyll, the presence of bluegreen algae subject to buoyancy responses that tend to bring them to the surface, and the formation of algal scums at the surface. It is probably fair to say that Cherry Creek Reservoir is poised in the transition zone between moderate and severe eutrophication. Nutrient enrichment of the reservoir is likely to push the condition more toward severe eutrophication. Phosphorus is especially important, given that the nuisance blooms are often composed of algae that have the ability to fix nitrogen (i.e., obtain nitrogen from the atmosphere). It is important that further phosphorus enrichment of the reservoir not occur. A more difficult question is whether the present level of phosphorus enrichment is satisfactory, or whether it should be scaled back. A good answer to this question is not possible given that the data set on phosphorus is flawed and difficult to interpret.

Dissolved Oxygen

Most lakes of moderate to great depth develop some degree of oxygen depletion near the bottom during the summer stratification season, and also sometimes during the winter under ice. Very shallow lakes may not develop much summertime oxygen depletion because of daily mixing, which renews the oxygen near the bottom. Cherry Creek Reservoir is transitional in the sense that it does show some vertical mixing even during the summer, but it does not mix vigorously on a daily basis from top to bottom. The oxygen data from the monitoring program indicate that oxygen remains well above zero near the bottom of the lake at all times. If the lake were deeper, but in other respects entirely the same, more severe oxygen depletion would probably occur. For example, both Standley Lake and Chatfield

Reservoir, which are deeper than Cherry Creek Reservoir, develop anoxic (oxygen-free) or nearly anoxic conditions near the bottom during the summer.

The presence of oxygen near the bottom of Cherry Creek Reservoir is beneficial in several respects. First, it allows colonization of the entire bottom of the lake by invertebrate organisms that require oxygen, and it allows full use of the lake bottom by fishes. Even more importantly, the presence of oxygen in water overlying sediments reduces the transfer of dissolved solids, including nutrients, from the sediments to the water. Sediments are always much richer in nutrients per unit volume than the overlying water. The main factor affecting the transfer of nutrients from sediments to water is the permeability of the sediment-water interface. Complete loss of oxygen increases permeability of the interface and converts a number of substances from insoluble to soluble form, thus leading to enrichment of the overlying water with dissolved solids, including nutrients. Oxidized sediment surfaces show much lower rates of transfer. Consequently, it is important that the oxidized condition of the sediment surface be maintained in Cherry Creek Reservoir.

Aside from depth, which has an important effect on the potential for oxygen depletion near the sediments, probably the most important factor affecting oxygen depletion near the sediments is the organic loading rate to the sediment surface. The organic loading rate is controlled by the rate of growth of algae in the overlying waters. Much of the algal production is transferred from the water column to the sediments in the form of nonliving organic matter, which might consist of dead phytoplankton cells or of fecal material from grazing organisms that eat the algae. This material accumulates at the sediment surface, where it decays and thus uses up oxygen. This causes disappearance of oxygen from the water just over the sediment. If the rate of algal growth is increased, the rate of organic loading to the sediment will also be increased, and the rate of oxygen loss above the sediment will increase as well. Thus factors causing an increase in the abundance or production of algae are likely to decrease the oxygen concentration above the sediments in a lake.

The nutrient enrichment of a lake leading to higher amounts of algal biomass and algal production may have a positive feedback or multiplier effect on the trophic state of a lake because of the connection between abundance of algae and amounts of oxygen near the bottom of a lake. When sufficient nutrients are added to cause organic loading that leads to complete oxygen depletion, the lake develops a magnified internal source of phosphorus as a result of the increased transfer of phosphorus from the sediments to the overlying water. Therefore, for management purposes, it is especially important to keep a lake from crossing the threshold that separates oxidized surface sediments from anoxic surface sediments. Cherry Creek Reservoir presently occupies the favorable side of this spectrum, and it is important that it not be pushed to the unfavorable side.

Total Dissolved Solids

Measurements of total dissolved solids have been part of the Cherry Creek monitoring program since its inception. Total dissolved solids can be estimated from field measurements of specific conductance, which are easy to make because they simply involve the use of a meter. Unfortunately, the meter that was used in much of the work on Cherry Creek Reservoir appears to have been poorly calibrated, and the measurements are therefore unreliable. However, it would make sense to continue making conductance measurements if a reliable measurement program can be established.

As pointed out by Knowlton and Jones in their review of the data base, the conductance data have little significance in the evaluation of trophic state. However, information on total dissolved solids (conductance) may be quite useful in helping to track sources of water reaching the reservoir. In fact, it is possible that information on total dissolved solids, when supplemented with a breakdown of the major components of dissolved solids, might be of great use in separating water sources for Cherry Creek Reservoir.

Total Suspended Solids

The most severe environmental threat to Cherry Creek Reservoir in the past has been filling of the reservoir with suspended solids. Fortunately, this problem was recognized over a decade ago and has now been dealt with effectively. However, it is important that programs for the monitoring and control of suspended solids be continued and extended. In forecasting changes in the physical characteristics of the reservoir, it is essential that the total annual transport of suspended solids to the reservoir be estimated. These estimates, when extrapolated over the next couple of decades, may indicate that control of suspended solids is now satisfactory, or may provide justification for more vigorous control of suspended solids as a means of preserving the useful life of the reservoir.

One unresolved problem is the duration of suspension for solids entering the reservoir from the watershed, and the extent of resuspension for solids that lie in shallow water subject to wave action. These problems could be worked out by separation of total solids into fractions (see recommendations below).

Recommendations for Monitoring

Monitoring of water flow, mass transport of phosphorus and suspended solids, and trophic state variables is important and should continue. The uses of this information are as follows: (1) to demonstrate compliance with water quality standards, (2) to allow management to anticipate water quality problems before they become severe, (3) to provide the basis for interception of nutrients and sediments, if necessary, before they reach the lake, (4) to support causal analysis of changes in the water quality of the lake or the watershed. The cost of water quality monitoring, although not trivial, is well justified by the avoidance of management errors or misdirection of management activities.

Management of water quality requires specific kinds of information, as shown by Table 2. As indicated by the table, much of this information is unavailable or unreliable for Cherry Creek Reservoir and its watershed. This makes planning and management more difficult, and more subject to judgment errors.

It is important that the monitoring data be reliable, and that the methods or limits of analyses be set by the requirements of the program rather than by the preferences of analytical laboratories or arbitrary choices by the analyst. Cherry Creek monitoring has been plagued to an abnormal degree with data quality problems, and this situation needs to be reversed. Useful routine monitoring occurs at many locations throughout the United States, and should not be considered inherently difficult or unfeasible.

Frequency of Monitoring

Routine monitoring of the lake should extend through the year, and should be 2-3 times more frequent during the warm season than during the cool season. The total number of sampling dates per year should be about 18 to give appropriate statistical limits for annual averages. More frequent monitoring during warm weather gives better resolution of events under biological control, given that all metabolic processes operate more rapidly in warm water, and also covers the season of greatest loading. Some sampling during the winter is important because the interpretation of some events occurring in lakes must be referenced to carryover from winter conditions.

Sampling in the watershed should follow two patterns: routine sampling of base flows, and sampling of all significant storm flows. The baseflow sampling should be coordinated with the lake sampling, and should involve approximately the same number of sampling dates and the same clustering during warmer weather. The stormflow sampling can be based either on automated sampling gear or on a combination of automated gear and manual sampling. Some sampling of this type has already been done in Shop Creek, but it needs to be extended to all major loading sources for Cherry Creek Reservoir.

Routine Sampling Stations

Routine sampling stations must include at least one point above the park boundary (e.g. near the Arapahoe gage) where both groundwater and surface flow (which will be storm flow or wet weather flow) are sampled routinely. In addition, the Cottonwood Creek sampling site is important, as is Shop Creek site. Special studies of the nutrient removal efficiency of the Shop Creek system can probably be terminated at some point, but the total output from the system needs to be measured as part of the routine monitoring program. In addition, the sampling network must include surface and storm flow samples from all channels that reach the margin of Cherry Creek, and should include samples of seepage water exiting the flats at the upper end of Cherry Creek Reservoir. Special arrangements should be made for the measurement of flows through the channels reaching the lake margin. This may require the installation of flumes and, given that the flumes will not be situated in ideal locations, they may need to be calibrated empirically rather than used with standard reference tables. However, it is important that this flow be measured and that it be sampled for water quality as well. The outflow from the reservoir should always be sampled when it is flowing, even if the flow does not coincide with a routine sampling date.

An effort should be made to estimate the flow from the reservoir to points downstream. If this is a difficult undertaking, which it may be, it can be done as a special study rather than routine monitoring, but it is important for proper closure of the water budget. Continued measurement of precipitation and evaporation are also important.

Cherry Creek Reservoir should be sampled at three locations, one of which can be designated the main station. The main station can be near the outlet tower, which has been the most consistent point of sampling in the past. At the main station, samples should be taken at three depths (near surface, midwater, and 0.5 m above the bottom), except for temperature and oxygen, which can be measured at closer intervals by the use of meters. At the two supplementary stations, only the surface sample is necessary. The samples should not be composited or combined.

Analytical Coverage

The samples of surface flow and groundwater should be analyzed for total dissolved solids (by means of conductance), temperature, soluble reactive phosphorus, total dissolved phosphorus, particulate phosphorus and nitrate, as well as total suspended solids. The lake sampling program should include temperature, transparency, dissolved oxygen, total dissolved solids (by conductance), total suspended solids, soluble reactive phosphorus, total dissolved phosphorus, particulate phosphorus, nitrate, chlorophyll *a*, particulate organic carbon, and phytoplankton composition (numerical and volumetric).

Discontinuation of Selected Studies

Studies of Nutrient Limitation and Nutrient Processing in the Lake

In the past, the Authority has supported a number of studies of nutrient limitation and nutrient processing in Cherry Creek Reservoir. Without exception, these experiments have been inadequate to lead to any firm conclusions. Enrichment experiments have been too artificial (limnocorrals) or too few (small enclosures) to lead to any general conclusions about the occurrence of phosphorus and nitrogen limitation in the lake. Studies of nutrient mobilization from sediments have been too few and have produced such variable results that they cannot support any general conclusions. Studies of this type are of little use unless they are definitive.

The arguments for continued study of nutrient limitation and nutrient cycling in the reservoir are presently weak, particularly in view of the urgent need for additional information on nutrient transport and on the connection between land use and nutrient transport. In order for studies of nutrient limitation to be justified, there needs to be some connection to possible management strategies. If the algae of the lake are predominantly phosphorus limited, a phosphorus control strategy is obviously justified. If the phytoplankton are nitrogen limited, phosphorus control is also justified because it offers the only potential for suppressing the growth of nitrogen-fixing bluegreen algae. Therefore, the management of trophic state is not presently affected by the outcome of experiments related to limiting nutrients.

Experiments on the mobilization of nutrients from the sediment would need to be far more extensive and sophisticated than they have been in order to provide meaningful information. Even if the fluxes of phosphorus from the sediments could be estimated accurately, additional studies would be needed to quantify fluxes of phosphorus to the sediments and temporal and spatial variation in all fluxes. Furthermore, knowledge of these fluxes would not necessarily have much bearing on the importance of managing external load. Further investment in these kinds of studies does not seem justified at the present time.

Summary of New Special Studies Beyond Routine Monitoring

Special projects may be important in answering specific questions that bear on management decisions. What follows is a description of projects that appear to be well motivated at present.

Studies of Sedimentation

The sedimentation rates for phosphorus and for total suspended solids in Cherry Creek Reservoir have never been explicitly studied. Such studies are important in supporting predictions of phosphorus concentrations that might result from various amounts and kinds of external loading. It is likely that such studies would demonstrate that the sedimentation rate for phosphorus entering the lake by storm flows is far higher than for phosphorus entering the lake by base flows. This might result in the creation of a two-compartment model for predicting phosphorus concentrations in relation to phosphorus loads.

Nutrient Transport and Conversion Across the Lakeside Wetland

Transect studies should be used to demonstrate the change in quality of water between the upper and lower end of the wetland above the reservoir. Such information will be useful in predicting the value of nutrient control in the watershed.

Establishing Estimates of Background Concentrations

Given that the background concentrations for the watershed are a matter of some controversy in relation to standards, it would be potentially quite useful for a one- or two-year study to be done of one or more areas draining subwatersheds that are minimally disturbed.

The studies of such watersheds should include both ground water and storm flow, and should be conducted according to mass balance principles. The raw data cannot be used directly to forecast background concentrations of the lake, because allowance must be made for sedimentation. However, given the results of the sedimentation studies recommended above, it should ultimately be possible to estimate the background concentrations for the lake.

Association Between Nutrient Yield and Land Use

For nutrient management and forecasting purposes, it is important that some information be collected on the relationship between nutrient yield and land use. Such studies should be conducted by mass balance principles and should include both storm flow and ground water. One point of major concern is residential development, which changes water yield. It should be possible to forecast a change in nutrient export associated with various kinds of development in Cherry Creek Basin.

Estimate of Water Flow Beneath Cherry Creek

A provisional estimate has been made of the flow of water beneath the Cherry Creek Dam. Because this estimate is based on calculations rather than measurements, it is important that some empirical studies be done. This information is important not so much for its own sake as for the more accurate calculation of inflows to Cherry Creek Reservoir.

Evaluation of Management Strategies

The Shop Creek project is an excellent example of water quality control. A number of other projects have been studied or at least discussed over the past several years. These projects can be put into three groups: (1) projects that are now advisable and feasible, (2) projects that should be deferred or that require further study, (3) projects that are probably inadvisable (Table 3).

Sediment and Nutrient Control on Drainages Near the Reservoir

There has been some discussion of sediment and phosphorus control projects on Cottonwood Creek and on Lonetree and Windmill drainages. These projects would involve construction of check dams leading to the trapping of sediment and the formation of more extensive wetland and riparian zones on these creeks. Projects of this type are justified by three kinds of benefits: (1) interception of phosphorus and sediment that might otherwise reach the reservoir, (2) aesthetic improvement in the drainages themselves, and (3) creation of new riparian and wetland habitat.

Dredging the Reservoir

If the reservoir loses substantial additional volume, dredging may be the only way in which its uses can be restored. For the present, however, it seems more prudent and cost effective to continue increasing the efficiency with which sediment is intercepted before it reaches the lake, thus greatly slowing the accumulation of sediment in the reservoir.

There are several arguments against dredging under present circumstances. First, the shallow end of the reservoir provides insufficient depth for power boats, and this creates a natural refuge zone for water birds and other wildlife. In addition, many species of water birds are specifically attracted to extensive areas of shallow water such as those found at the upper end of Cherry Creek.

Dredging on a sufficient scale to have much effect on the reservoir would pose some serious environmental problems. If the sediment were trucked from the area, as presumably it would have to be, the noise and disturbance would be quite substantial and would extend over a long period of time. Some of the beneficial effects of dredging might be offset by accelerated transport of sediments from the upper end of the basin and the wetland area to deeper water as a result of dredging.

Control of Shoreline Erosion

Site inspection shows that an erosion problem is associated with specific water level changes. One possible means of managing erosion would be to work with the Corps of Engineers to assure that water levels remain within a zone of minimum erosion corresponding to historic mean levels.

Active management of shoreline erosion is also possible, although it may not be necessary if water levels are held within specific bounds. Installation of rip rap, gabions or even vegetation in sufficient amounts to control erosion completely might interfere with the accessibility and usefulness of the lake margin. Many visitors to the lake presently use the smooth near-shore area as a place to walk or fish.

The priority for active control of shoreline erosion is probably only for areas that show the highest rates of erosion, and only if these areas cannot be managed by restrictions on water level.

Additional Regulation of Treatment Plant Practices

Restrictions have been placed on practices of wastewater treatment plants for treatment and disposal of effluent. The restrictions are logical given the very high concentrations of phosphorus found in secondary effluent. However, an important question at present is whether or not additional restrictions can be justified by the need to intercept phosphorus that might enter Cherry Creek Reservoir. The information at hand is insufficient to provide an answer to this question. Progress should be made toward better definition of the pathways of phosphorus flow to Cherry Creek Reservoir, which will set the stage for a meaningful evaluation of restrictions on phosphorus in wastewaters.

Re-examination of the Phosphorus Standard

The phosphorus standard should be re-examined in collaboration with the Colorado State Department of Health Water Quality Control Division. This will require a better information base than now exists. Pathways for phosphorus loading of the reservoir must be understood better, and there must be some quantitative information on background concentrations of phosphorus originating in portions of the watershed that are not heavily used.

Aeration

Aeration is sometimes used in lakes that suffer high degrees of eutrophication. Aeration can be helpful in two ways. First, it may change the species composition of algae, thus shifting the balance from species that are more likely to cause nuisances to species that are less likely to do so. In addition, aeration of lakes that are strongly stratified may disrupt stratification sufficiently to allow oxygen to reach anoxic sediments. Neither of these two justifications seems particularly compelling for Cherry Creek Reservoir at the present time. The incidence of nuisance blooms of algae is relatively small. Aeration is not always effective in disrupting or replacing these blooms, and in some cases causes changes that are even less desirable than the original condition. The potentially stronger justification in some lakes is disruption of stratification, but stratification is very weak in Cherry Creek Reservoir, and there is no severe oxygen depletion over the sediments.

References

Denver Regional Council of Governments. 1984. Cherry Creek Reservoir Clean Lakes Study.

Knowlton, M.F. and J.R. Jones. 1993. Limnological Investigations of Cherry Creek Lake. Final report.

Special Features	Possible Effects
Low reservoir hydraulic residence time	Algal populations are not affected by flushing
High ratio of watershed to lake area; low runoff	Lower and upper watershed segments may have differential effects
Pumping from alluvium	Interception of nutrients
Large wetland near reservoir	Interception of nutrients
Low mean depth for reservoir	Reduced likelihood of oxygen depletion, higher probability of nuisance blooms
Storm loading prominent	High suspended solids transport and irregular sedimentation rates

Table 1. Features Cherry Creek Reservoir and watershed of particular importance in sampling and the interpretation of data.

Information	Purpose	Availability for Cherry Creek
Water budget for reservoir	Quantification and tracking of nutrients	Incomplete: groundwater undocumented
Water budget for watershed	Apportionment of nutrients by land use	No information
P concentrations by fraction for all major sources and the lake	Quantification of P loads, sources	Flawed and incomplete data
Chlorophyll concentrations for the lake	Quantification of algal populations	Flawed data
Transparency data for the lake	Quantification of the appearance of the lake	Probably OK
Oxygen data for the lake	Quantification of deepwater oxygen	Probably OK
Temperature data	Documentation of stratification, mixing	Probably OK
Algal composition	Documentation of shifts to nuisance species	Incomplete
Inorganic N data	Representation of N limitation	Flawed data

Table 2. Basic requirements for studies of lake trophic status and nutrient control.

Study and Management Options	Recommendation
Studies	
Studies of Nutrient Limitation and Nutrient Processing in the Lake	Discontinue
Studies of Sedimentation	Add
Nutrient Transport and Conversion Across the Lakeside Wetland	Add
Establishing Estimates of Background Concentrations	Add
Association Between Nutrient Yield and Land Use	Add
Estimate of Water Flow Beneath Cherry Creek	Add
Routine Monitoring	Continue
Management	
Sediment and Nutrient Control on Drainages Near the Reservoir	Recommended
Dredging the Reservoir	Not recommended
Control of Shoreline Erosion	Recommended (via water level regulation)
Additional Regulation of Treatment Plant Practices	Defer pending study
Re-examination of the Phosphorus Standard	Recommended
Aeration	Not recommended

Table 3. Summary of possible studies and management options.

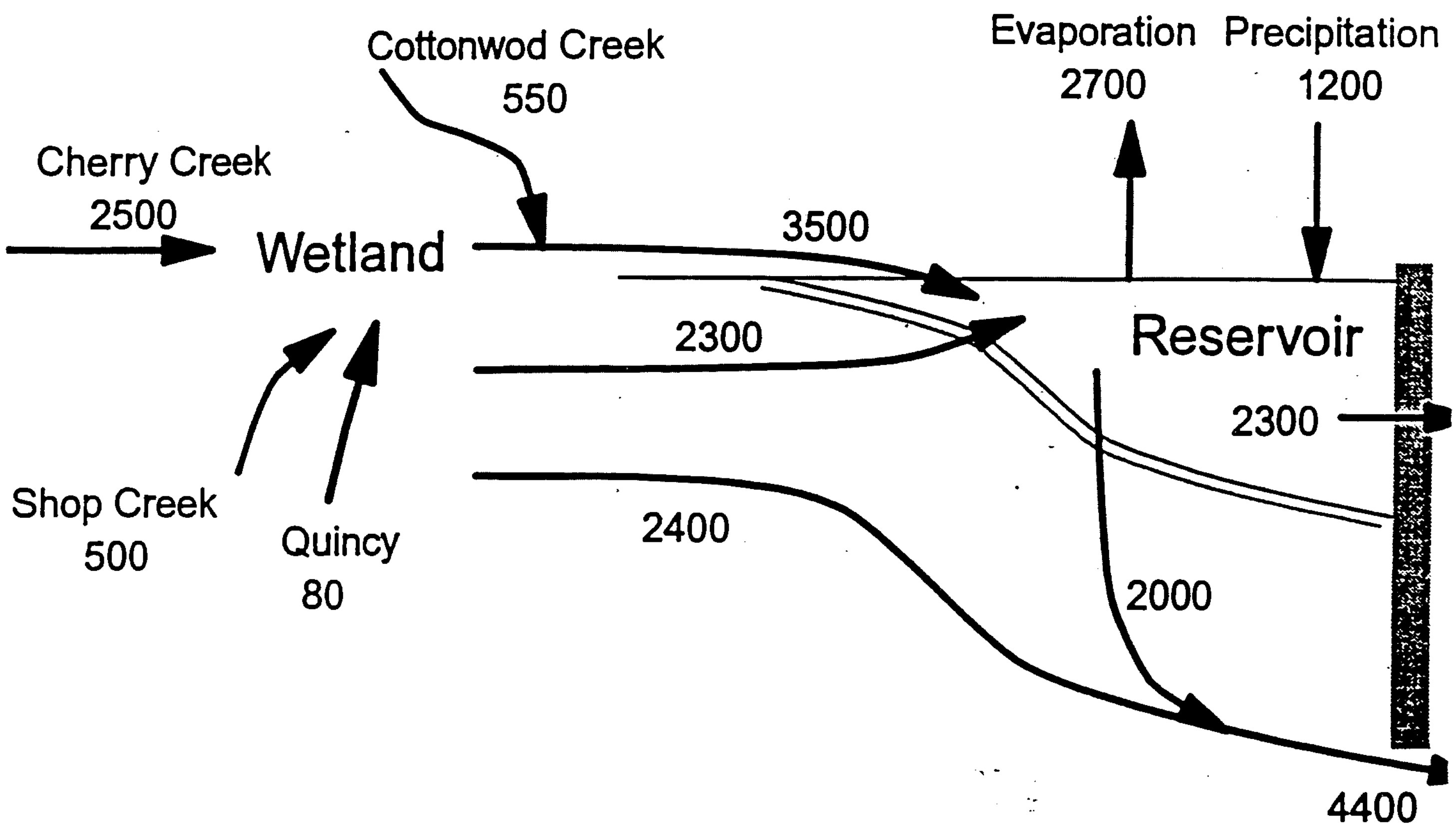

Figure 1. Approximate mean annual water budget of Cherry Creek Reservoir (acre-feet per year; from various sources).