Montana and Idaho Border Nutrient Load Agreement TECHNICAL GUIDANCE

Presented to
Montana Department of Environmental Quality
Idaho Department of Environmental Quality

Submitted by
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TECHNICAL GUIDANCE

Montana and Idaho Border
Nutrient Load Agreement for Pend Oreille Lake Open Water

GOAL	Protect Pend Oreille Lake open water quality
WATERS AFFECTED	Pend Oreille Lake and Clark Fork River
TARGETS	• An area-weighted euphotic-zone average concentration of 7.3 ug/l total phosphorus for Pend Oreille Lake • Total loading to Pend Oreille Lake of 328,651 kg/yr total phosphorus • 259,500 kg/yr total phosphorus from Montana (Clark Fork River at Montana/Idaho state line) • 69,151 kg/yr total phosphorus from the Pend Oreille Lake watershed in Idaho • Greater than a 15:1 total nitrogen to total phosphorus ratio
AREA PROTECTED	Open waters of the lake (waters where the maximum depth is greater than 2.5 times water transparency as measured by Secchi depth) from the mouth of the Clark Fork River to the Long Bridge (Highway 95.) See Attachment C, Map of Pend Oreille Lake.

I. Technical Guidance Summary

In September 1999, the Tri-State Water Quality Council (Council) created a Technical Team to develop technical guidance for an agreement between the states of Montana and Idaho for establishing nutrient targets and apportioning loads to Pend Oreille Lake. The impetus for developing the targets was concern over maintaining the water quality of the open waters of Pend Oreille Lake and the need to address potential impacts from the

Clark Fork River in Montana and local sources in Idaho. The Technical Team's charge was to set open water nutrient concentration targets which support the lake's designated beneficial uses, and nutrient loading targets to meet those concentrations. The team reviewed and analyzed existing data on Pend Oreille Lake and the Clark Fork to establish a solid scientific foundation for technical guidance and a proposed agreement for consideration by the two states. Team members included representatives from Montana Department of Environmental Quality (MDEQ), Idaho Department of Environmental Quality (IDEQ), the University of Idaho, and the Clark Fork Coalition. The U.S. Environmental Protection Agency (EPA) Regions 8 and 10, and the U.S. Geological Survey, participated in the team in an advisory capacity. Land & Water Consulting, contractor to the Council, provided technical expertise to the team.

Driven by citizen concerns over Pend Oreille Lake water quality, the Council, MDEQ, IDEQ and EPA concurred that development of nutrient targets at the Montana/Idaho border would be timely to help prevent pollution of the lake's open waters. Because about 90 percent of the flow and 80 percent of the loading of total phosphorus into Pend Oreille Lake comes from the Clark Fork River, targets are established for the Clark Fork River at the border to address this predominate influence on lake water quality. By establishing these targets, a major objective of the Clark Fork-Pend Oreille Watershed Management Plan is fulfilled, which is to protect Pend Oreille Lake water quality by maintaining or reducing the rate of nutrient loading from Montana's Clark Fork River, as well as reducing nutrient loading from the lake's watershed in Idaho. The targets focus on the lake's open water and do not address the nearshore, shallow areas of the lake that are influenced predominately by sources located within one mile of the shoreline. Nearshore issues will be addressed in a future document.

Establishing targets at the interstate boundary will help apportion nutrient management responsibilities between the two states for future water quality planning and implementation activities. The targets will also provide a framework for water quality management decisions related to new sources.

The goal of the nutrient loading targets is to protect open lake water quality. To reach this goal, an area-weighted euphotic zone concentration target for Pend Oreille Lake of 7.3 ug/l total phosphorus is recommended by the Technical Team. To meet this target, a total load of 328,651 kg/yr. total phosphorus is recommended to be allocated as follows:

- 259,500 kg/yr total phosphorus from Montana (Clark Fork River at Montana/Idaho state line;) and
- 69,151 kg.yr total phosphorus from the Pend Oreille Lake watershed in Idaho.

Additionally, the team recommends maintenance of a ratio greater than 15:1 total nitrogen to total phosphorus. Set as an action level, a 15:1 ratio is a desirable lower limit to avoid the occurrence of algal blooms in Pend Oreille Lake.

II. Background

A. Clark Fork-Pend Oreille Project History

In response to citizen concerns and complaints about the growing presence of algae in the Clark Fork-Pend Oreille watershed, in 1987 U.S. Congress mandated EPA to conduct a comprehensive water quality study in the three-state basin and to report study findings and recommendations to Congress. Authorized in the Clean Water Act, this study was known as the Section 525 Clark Fork-Pend Oreille Basin Water Quality Study. Regions 8 and 10 of EPA had primary federal responsibility for implementing the study, while the states of Montana, Idaho and Washington identified research objectives within their boundaries, conducted the research, wrote reports and recommended state-specific management actions to meet the basin-wide study objectives. A steering committee consisting of representatives from EPA and the three states oversaw the study and reviewed and summarized the three state plans into a document titled: <u>Clark Fork-Pend Oreille Basin Water Quality Study: A Summary of Findings and a Management Plan.</u> Following a series of basin-wide pubic hearings, the management plan was finalized in 1993.

The plan focuses on the control of nutrients and eutrophication in the three-state basin, and its goal is to restore and protect designated beneficial water uses basinwide. To meet the goal, the plan establishes four objectives:

1. Control nuisance algae in the Clark Fork River by reducing nutrient concentrations.
2. Protect Pend Oreille Lake water quality by maintaining or reducing current rates of nutrient loading from the Clark Fork River.
3. Reduce nearshore eutrophication in Pend Oreille Lake by reducing nutrient loading from local sources.
4. Improve Pend Oreille River water quality through macrophyte management and tributary nonpoint source controls.

The watershed management plan is being implemented by the Council, a broad-based 28-member group established by EPA and the three states in October 1993. In addition to setting policy and direction for water quality management actions, the Council oversees the efforts of various subcommittees who are working in local communities throughout the watershed to carry out priority actions from the plan. One of the top priorities in the plan is the development of nutrient targets and nutrient reduction strategies for the Clark Fork River and Pend Oreille Lake. The Council's work to meet the four management plan objectives can be summarized as follows:

Management Plan Objective 1:
Control nuisance algae in the Clark Fork River by reducing nutrient concentrations.

Work on the Clark Fork River targets began in 1994 when a Nutrient Target subcommittee was established by the Council to forge numeric targets and a workable implementation plan for meeting those targets. The process was driven by 303(d) requirements of the federal Clean Water Act and the State of Montana's responsibility under Section 303(d) to develop a TMDL. However, in 1995 the Council decided to take a voluntary approach rather than a mandatory, permitted approach. With approval from MDEQ and EPA to proceed with development of a voluntary program, the subcommittee wrestled with the complex scientific and policy issues associated with the reduction of nutrient loading. After four years of work the group completed the Clark Fork Voluntary Nutrient Reduction Program (VNRP), which was approved by EPA Region 8 in October 1998 as a functionally equivalent TMDL for the river.

The goal of the Clark Fork VNRP is to restore beneficial uses and eliminate nuisance algae growth in the river from Warm Springs Creek to the Flathead River confluence. To meet the goal, the VNRP sets numeric targets for chlorophyll-*a*, total phosphorus, and total nitrogen[1] for 200 miles of river and sets site-specific measures to meet the targets over a ten-year period. The VNRP includes commitments for specific actions to be taken by each of the four key point source dischargers (the three cities of Butte, Deer Lodge, Missoula and Smurfit-Stone Container Corporation) and calls for reductions from other point sources and key non-point sources to reach the numeric targets.

Management Plan Objective 2:
Protect Pend Oreille Lake water quality by maintaining or reducing current rates of nutrient loading from the Clark Fork River.

Having been successful in reaching consensus on goals and a strategy to significantly reduce nutrients and algae on the Clark Fork River, the Council focused its attention downstream of the VNRP to prevent pollution of Idaho's Pend Oreille Lake. Council members along with EPA and both states agreed that a nutrient loading target at the border would be instrumental in preventing increased cultural eutrophication to the lake's open water. As noted above, since about 90 percent of the flow and 80 percent of the loading of total phosphorus into Pend Oreille Lake comes from the Clark Fork River, targets are established at the border to address this predominate influence on the lake's open water. It was further agreed that targets at the border would provide the basis for a coordinated interstate management approach by apportioning responsibilities between the two states for protecting the lake. After a series of conference calls during 1999, representatives of the Council, EPA Region 8 and 10, and the states of Montana and Idaho made the decision to proceed with development of a target for the lake. A work plan was developed in November 1999 and signed by MDEQ and IDEQ indicating the agencies' support of the border agreement approach. The team began its work in early 2000 and presented its technical findings and recommended targets to the Council in October 2000. At that time the team also presented a draft agreement for the states'

[1] Targets for the Clark Fork mainstem are:

- 100 mg/square meter (summer mean) and 150 mg/square meter (peak) chlorophyll-*a*, at any site, for the entire Clark Fork River area of the VNRP;
- 20 ug/l total phosphorus upstream of the Reserve Street bridge at Missoula, where Cladophora is a problem and the 15:1 N:P ratio should be maintained;
- 39 ug/l total phosphorus downstream of the Reserve Street bridge at Missoula; and
- 300 ug/l total nitrogen.

consideration as a possible format for describing Montana and Idaho responsibilities and roles in meeting the targets. The Council presented the Technical Guidance and agreement documents to the two states in February 2001.

Management Plan Objective 3:
Reduce nearshore eutrophication in Pend Oreille Lake by reducing nutrient loading from local sources.

Once the open lake targets of the border agreement are finalized, the Council will begin work with IDEQ and local stakeholders on a nutrient management strategy to reduce impacts from nearshore nutrient sources affecting the lake's shallow bays. (See brief discussion on nearshore issues, Page 7.)

Management Plan Objective 4:
Improve Pend Oreille River water quality through macrophyte management and tributary nonpoint source controls.

Once the lake nutrient management strategy is completed, the Council will work with IDEQ and the Washington Department of Ecology (DOE) on a coordinated approach to address issues in the Pend Oreille River in Idaho and Washington. In Washington, the Council has been participating with DOE, the Pend Oreille Conservation District, the Pend Oreille Public Utility District and other entities in local watershed planning efforts already underway in Pend Oreille County.

B. Overview of the Clark Fork-Pend Oreille Watershed

The Clark Fork-Pend Oreille watershed encompasses nearly 26,000 square miles in western Montana, northern Idaho and northeastern Washington. The Clark Fork River, Pend Oreille Lake and Pend Oreille River are among the main bodies of water in the basin. The Clark Fork River begins along the west slopes of the Continental Divide and drains much of western Montana before entering Pend Oreille Lake. The lake is the source of the Pend Oreille River, which flows into northeastern Washington. The waters then enter the Columbia River. Highly valued recreational and economic resources characterize the watershed. Timber, mining, fish, wildlife, water, rangeland and croplands support a variety of human uses, ranging from logging and agriculture to recreational fishing and boating.

Concerns about environmental problems in the basin are longstanding (EPA 1993). The two greatest concerns are pollution from heavy metals from past mining and smelting activities in the headwaters of the Clark Fork River and eutrophication problems caused by excessive nutrients.[2] Eutrophication manifests itself in the Clark Fork River in

[2] At the beginning of the Section 525 studies, the steering committee decided to restrict the studies to nutrients because they are the primary interstate water quality issue and affect the largest portion of the watershed. The steering committee also concurred that remedial actions on metals were already well underway through the federal Superfund program. Thus, the focus of the Council's work to reduce pollution in the watershed is on nutrients.

Montana as nuisance levels of attached and filamentous algae that impair most designated uses of the river. In Pend Oreille Lake, increasing growths of algae and other aquatic plants in nearshore areas and public perception of decreasing water clarity are the primary water quality concerns. In Washington, the Pend Oreille River is choked with heavy growth of aquatic plants that impede boat traffic and most other uses.

C. Overview of the Pend Oreille Lake Problem Assessment

Due to uncertainties about maintaining lake water quality especially in near shore areas, Pend Oreille Lake was added to the State of Idaho's 1994 Section 303(d) list –and retained on the 1996 list—as a "threatened" waterbody. Because of this listing, IDEQ prepared a problem assessment on the lake (DEQ 1999) which included the following elements, as briefly summarized here:

1. Physical and Biological Characteristics

Pend Oreille Lake is the largest and deepest natural lake in Idaho and is recognized throughout the Inland Northwest as an extremely valuable water resource. The surface area of the lake is 91,180 acres. Lake levels are controlled by Albeni Falls dam operated by the U. S. Army Corps of Engineers near the Idaho/Washington boundary. Eighty three percent of the lake's watershed is forested (Eastern Washington University 1991). While nearly 65 percent of the lakeshore is in National Forest, almost half of all developable land in the lake's watershed is located within one mile of the lakeshore. Development pressure predicted by population growth figures will likely be concentrated fairly close to the lake because of the location of these lands (Hoelscher *et al*. 1993).

Pend Oreille Lake's designated uses are water supply, recreation, salmonid spawning, cold-water biota, wildlife habitat and aesthetics. The lake supports a significant sport fishery [in1991, anglers expended an estimated 465,000 hours fishing the lake (Corsi *et al*. 1998) and the world record bull trout, weighing 32 pounds, was taken from the lake in 1949] and is a main water source for many homes along its shores.

2. Pollutant Source Inventory

Point sources: Of the four point sources (Cabinet Gorge Dam, Cabinet Gorge Fish Hatchery, Clark Fork Hatchery and Kootenai-Ponderay Sewer District), only one discharges directly into the lake. The sewer district of the cities of Kootenai and Ponderay each year discharges 1,432 kg. total phosphorus and 9,929 kg. total nitrogen into Boyer Slough (Hoelscher *et al*. 1993).

Non-point sources: Non-point sources that contribute nutrients to the lake are the result of land disturbing activities such as residential development, silviculture, agriculture, grazing. Atmospheric deposition, septic tanks, and urban runoff are also sources of nutrients. The areas of highest algae growth along the lakeshore are areas of higher residential development (Falter *et al*. 1992). Phosphorus and nitrogen also enter the lake from tributary streams, most notably the Pack River, Lightning Creek and Sand Creek (Frenzel 1991b).

3. Water Quality Concerns and Status

The primary water quality concerns for the lake are: nutrients, metals, gas saturation (from Cabinet Gorge and Noxon Rapids hydroelectric dams), fisheries (Endangered Species Act listed bull trout), and Eurasian Milfoil (a non-native aquatic weed that forms dense weed beds and can severely restrict beneficial uses). Due to the water level fluctuations and shoreline development, bank erosion is severe in some areas (IDEQ 1999). The problem assessment also notes that as of 1999 none of the National Pollutant Discharge Elimination System (NPDES) permits for point sources were current, and that Idaho Water Quality Standards may not be protective of the lake from the standpoint of mixing zone requirements or cumulative effects from dischargers.

The State of Idaho Water Quality Standards include a narrative description for unacceptable levels of nutrients that states: "Surface waters of the state shall be free from excess nutrients that can cause visible slime growths or other nuisance aquatic growths impairing designated beneficial uses." The lake is afforded additional protection by being designated by the State as a Special Resource Water. Because of this designation, no new point sources are allowed and existing sources are limited to their current permit capacities. The Special Resource Water designation protects the lake from discharges that would cause a measurable reduction in ambient water quality below the applicable mixing zone.

Open lake water quality—which is predominantly influenced by the Clark Fork River—has not changed statistically since the mid-1950's (Beckwith 1989, Woods 1991a). However, Hoelscher *et al*. (1993) concluded that at the projected population growth rate, the difference between existing conditions (oligotrophic) and less desirable conditions (mesotrophic) would be reduced by approximately one half in twenty years. The population growth projected (population of 35,081 in Bonner County by 2010) by Hoelscher *et al*. (1993) was actually reached in 1998. Therefore, the growth pattern around the lake has reached the potential for being a very real threat to water quality.

4. Nearshore Water Quality Concerns

Population growth and shoreline development poses potential threats to nearshore and open lake water quality. Without nutrient management planning and implementation, excessive nutrients in the nearshore could impair the lake's aesthetic qualities, recreational uses and domestic water supplies (EPA 1993). Sources of these nutrients include residential development, roads, silviculture, septic tanks, and urban runoff. These sources will be addressed as part of the Council's future effort to meet Objective 3 of the management plan (to reduce nearshore eutrophication in the lake by reducing nutrient loading from local sources) through the development of a lake nutrient management strategy.

5. Problem Assessment Conclusions

   IDEQ's problem assessment recommends de-listing of the lake and EPA approved de-listing in 2000. However, the assessment recognizes that over the long term there remains concern that water quality of the lake could be degraded. The assessment therefore supports the Council in its future efforts to develop a nutrient management strategy for the lake.

D. Overview of Upstream Issues

Upper and middle Clark Fork River:
Although heavy metals pollution in the headwaters of the Clark Fork is the most acute problem in the upper basin, nutrient pollution affects the largest portion of the basin and is the primary interstate water quality issue. Excessive nutrients in the river originate from a combination of point and nonpoint sources. Ambient concentrations of phosphorus and nitrogen have led to blooms of filamentous algae in the river above Missoula and heavy growths of slime, or diatom algae, below Missoula. Algae impair beneficial uses of the river, such as irrigation and recreation, and in large concentrations can deplete dissolved oxygen needed by fish and other aquatic organisms. The 525 study showed that excessive levels of algae caused water use impairment in up to 250 miles of the Clark Fork, to its confluence with the Flathead River. This impairment was the basis for the development of the VNRP, as described on Pages 3-4. Most of the Clark Fork River, as well as its tributaries, is classified as a B-1 waterbody, which means that the river's quality shall be maintained for all beneficial uses.

Flathead River:
The Flathead River provides a large flow of water containing low concentrations of nutrients, which dilutes Clark Fork River water. The Flathead provides a source of dilution relative to the Clark Fork by contributing 67% of the water, 33% of the total phosphorus and 47% of the total nitrogen to the Clark Fork at Cabinet Gorge (based on 1984-99 record.) The 525 study showed locally important sources of nutrient loading in the Flathead watershed. Concerns about nutrient loading to Flathead Lake are being addressed through a TMDL for the lake and its watershed. Flathead Lake serves as a nutrient sink and is largely responsible for reduced downstream nutrient concentrations. Downstream of the lake, operation of Kerr Dam on the lower Flathead River causes fluctuating stream flows that can affect water quality and nutrient loading. Nutrient levels may also be affected by local sources in tributaries below Kerr Dam.

Lower Clark Fork River:
Below the Flathead River, the Clark Fork is characterized by very large streamflows and low nutrient concentrations. Reservoirs created by dams along the river at Noxon and

Cabinet Gorge act as nutrient sinks for river nutrients, but because of rapid flushing in these reservoirs the percent of total nutrient retention is small or variable (Beak 1997.) A review of existing data by Beak concluded that the retention of total phosphorus on an annual basis is probably on the order of 10 to 20 percent, although during low flow summer conditions retention in probably more substantial. Beak further concluded that algae in the reservoirs are probably more light-limited than nutrient-limited. Mass balance calculations based on data from 1984-1999 (MDEQ and Council) suggest that total phosphorus retention over the 16 year period was on the order of 25% (Land & Water 2000).

Control strategies for curbing nutrient loading in Montana's Clark Fork River basin are being implemented through the VNRP and the Flathead TMDL. However, new proposals could increase nutrient loading, such as a new point source discharge being proposed for a mine at Rock Creek on the lower Clark Fork which would introduce metals and nutrient pollution to the lower river and Pend Oreille Lake. The proposed mine project has not yet obtained an operating or discharge permit, however the Pend Oreille Lake targets would provide a basis for addressing this and other new sources so that water quality improvements made by nutrient control strategies in the basin are not jeopardized.

III. Existing Studies and Surveys

The first important task of the border agreement Technical Team was to research and review existing data on Pend Oreille Lake. The team assembled some of the members of the Section 525 study, including technical experts from IDEQ, MDEQ, the University of Idaho and U. S. Geological Survey, to review the study data as well as other data sources. The following discussion summarizes that review.

Public interest groups, industries and businesses, universities, local governments, and state and federal agencies have investigated the resources of Pend Oreille Lake to varying extent. Most of these efforts have been summarized by the Environmental Research Laboratory (1987), Beckwith (1989), Seifert (1989), Hoelscher (1993), and Hoelscher *et al.* (1993).

Fewer of these efforts focused on more traditional measures of water quality. Kemmerer and others visited Idaho early this century (Kemmerer *et al.* 1923; as cited in Rieman 1976). More recently, investigators have classified the pelagic, open waters of the lake as oligotrophic or nutrient poor (Stross 1954, Woods 1991a) tending toward mesotrophy or moderately nutrient enriched (Rieman 1976, Milligan *et al.* 1983, Beckwith 1989). The lake's great depth has been cited as an important factor in maintaining the oligotrophic characteristics (Stross 1954, Rieman 1976, Milligan *et al.* 1983, Watson *et al.* 1987, Woods 1991a). Comparisons with previous Pend Oreille Lake limnological data (Stross 1954, Platts 1958, Rieman 1976, Beckwith 1989) indicated no apparent changes in the trophic status (Platts 1958, Rieman 1976, Beckwith 1989, Woods 1991a). Beckwith (1989) and Woods (1991a) further reported no statistical differences in traditional measures of trophic state from the early 1950's to present. These data should be interpreted with caution because of differences in analytical methods, small sample size, and temporal and spatial variability.

Pend Oreille Lake is characterized by two distinct basins. The large, deep southern basin contains most (95%) of the lake's volume and has a mean depth of about 220 m (Woods 1991b). Water flowing into the southern basin will likely reside there in excess of ten years (Falter *et al.* 1992). The northern basin is much shallower with a mean depth of 29 m (Woods 1991b). Because of the smaller volume and the large flow of the Clark Fork River, water resides in the northern basin much less than one year (Falter *et al.* 1992).

A common feature among historical investigations was the strong influence exerted by the Clark Fork River on Pend Oreille Lake water quality (Stross 1954, Platts 1958, Rieman 1976, Beckwith 1989, Woods 1991a). This would be expected as most (90%) of the inflow to the lake is accounted for by the river (Frenzel 1991a). Studies have shown that the water quality of the open waters of the lake is influenced primarily by inflow from the Clark Fork River (Woods 1991b), while the water quality of the lake's nearshore zone is influenced to a greater extent by residential development and other local land use activities (Falter *et al*. 1992).

An often-used indicator of lake water quality is water clarity. The deeper, southern lake basin was found to be clearer than the shallower, northern part of Pend Oreille Lake (Stross 1954, Rieman 1976, Beckwith 1989, Woods 1991a). The greater clarity was attributed to the southern basin's depth and distance from the Clark Fork River. Suspended sediment in the river inflow, as well as re-suspended sediment from the lake bottom and near shore areas, were the main causes of lower water clarity along the north shore (Woods 1991a).

Nitrogen and phosphorus contribute to algae growth and either of these two nutrients can be limiting depending on their ratio. Phosphorus is the nutrient most often limiting algae and aquatic plants in the Pend Oreille Lake (Rieman 1976, Greene *et al.* 1984, Gangmark and Cummins 1987, Woods 1991a). Total phosphorus concentrations have been shown to increase from south to north (Woods 1991a). The south-to-north increase has been partially attributed to the Clark Fork River's input of suspended sediment. In nature, phosphorus is adsorbed to soil particles and enters surface waters from erosion of soils in the watershed. Nutrient concentrations were higher in the mid-1970's (Rieman 1976, U.S. Geological Survey 1976) than they were in the late 1980's and early 1990's (Woods 1991a). These comparisons need to be judged critically because of analytical methods and sample size. Beckwith (1989) further cautioned conclusions from these data as it is quite likely that average annual nutrient loads to the lake truly were higher during this period because of higher stream flows.

Although nitrogen limitation is common in the Clark Fork River (especially in late summer) Pend Oreille Lake is primarily phosphorus limited, with occasional nitrogen limitation in late summer in the north lake. (Falter, see Attachment D.) According to Falter's review of data and literature, the fact that the Clark Fork River is often nitrogen limited probably has little bearing on the limiting factor in most of the south lake or mid-lake. Algal assays in Pend Oreille Lake through the fall 1984 indicated primary phosphorus limitation with secondary limitation by nitrogen at all sites (Woods 1991a). Algal assays in the lake through summer-fall 1986 indicated primary phosphorus limitation and secondary nitrogen limitation in the north and mid-lake but exclusive phosphorus limitation in the south lake (Gangmark and Cummins 1987). As with many large lakes, the growth of algae in near shore areas of Pend Oreille Lake is attributed to nutrient enrichment from shoreline and lake nearshore sources.

Chlorophyll-*a*, the primary photosynthetic pigment of algae and aquatic plants, is a widely cited and accepted indicator of trophic state (Carlson 1977, Ryding and Rast 1989). Mean chlorophyll-*a* concentrations were low and spanned a narrow range (Woods 1991a). Allowing for differences in analytical methods, it appeared current chlorophyll-*a* concentrations (1989/1990) differed little from those measured nearly twenty years ago (U.S. Geological Survey 1976.) It has been stated Pend Oreille Lake primary productivity has been inhibited by the Clark Fork River's temperature (Platts 1958), turbidity (Rieman 1976) or a combination of the two (Stross 1954). The Environmental Research Laboratory (1987) modeled chlorophyll-*a* production using the lake average total phosphorus concentration and the conclusion was that algae production was not excessive.

Several data sources exist for establishing nutrient targets for Pend Oreille Lake and the Clark Fork River at the Montana-Idaho state line. The most temporally and spatially robust data for Pend Oreille Lake was collected during 1989 and 1990. The data is comprised of about 300 water samples taken at five lake stations (Woods 1991a). Precision of the data was analyzed with duplicate samples for quality-assurance purposes. The U.S. Geological Survey streamflow and nutrient concentration sampling below Cabinet Gorge Dam during those same years is the most rigorous for the Clark Fork River for 1989/90. The most continuous long term monitoring record began in 1984 with MDEQ's Clark Fork monitoring program that included sampling at multiple river sites, including below Cabinet Gorge dam. In 1998, MDEQ's nutrient concentration data record was continued by the Council's Monitoring Committee (Land & Water 1999). The Technical Team considered all of these data sets in establishing nutrient targets for Pend Oreille Lake.

IV. Nutrient Targets, Loading Analysis, Allocation and Monitoring

A. Assumptions

The Technical Team developed and agreed to the following assumptions prior to development of the nutrient targets:

1. **Current lake *open water* water quality is acceptable**.
   Data supports the assumption that *open water* water quality, which is predominantly influenced by the Clark Fork River, has not changed statistically since the 1950's. Historical data show that, in general, the lake was oligotrophic (nutrient poor) during

the early 1950's, mid-1970's, and late-1980's (Section 525 study[3].) As noted above, the 1999 lake problem assessment concluded designated beneficial uses—water supply, recreation, salmonid spawning, cold-water biota, wildlife habitat and aesthetics—are being supported. The lake is afforded extra protection through the Special Resource Water designation whereby water quality cannot be lowered to the point that beneficial uses would be impacted. Therefore, the goal of **maintenance** of lake water quality, as recommended in the Section 525 report, is acceptable.

2. **The targets cover Pend Oreille Lake to its western boundary at the Long Bridge.**
   As delineated by USGS, the area covered by the targets includes all of Pend Oreille Lake from the mouth of the Clark Fork River inflow to the Long Bridge (Highway 95.) See map, Attachment C.

3. **The focus of the nutrient targets is protection of the quality of the lake's open water.**
   Open water and nearshore areas of the lake require separate management approaches. The targets recommended in this guidance are for open water, not for nearshore areas around the lake. Open water is defined as waters where the maximum depth is greater than 2.5 times water transparency as measured by Secchi depth. The targets address Montana and Idaho sources that contribute to nutrient loading of open water. Nearshore water quality will be addressed in the future as a separate issue.

4. **The targets are based on findings from the Section 525 water quality study and the long term MDEQ data set.** Conducted during 1989 and 1990, the 525 study comprises the most comprehensive and complete analysis for the Clark Fork River and Pend Oreille Lake to date. Studies of the lake included nutrient and hydrologic budgets, pelagic zone limnology, near shore productivity, and a nutrient load/lake response model. The Technical Team is confident in the use of the 525 data based on the quantity, quality and representativeness of the data generated. The team also utilized data from MDEQ's long-term monitoring record to develop targets that consider yearly nutrient variation.

5. **The targets will be for total nutrients rather than soluble nutrients.**
   Using a data base consisting of 200 rivers to relate algal densities to nutrient concentrations, Dodds and Smith (1995) concluded that total nutrients were a better predictor than soluble nutrients. In lakes, limnological studies show that total nutrients have a better correlation with algae than soluble nutrients, and that total nitrogen and total phosphorus relate better to seasonal and lakewide productivity (see discussion on nitrogen and phosphorus, Attachment D.)

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[3] The Section 525 study concluded that extensive monitoring of the pelagic zone during the 1989 and 1990 water years indicated, on the basis of phosphorus, chlorophyll-*a* and nitrogen, Pend Oreille Lake was oligotrophic. Oligotrophy also was indicated by lakewide Secchi-disk readings; although Secchi-disk readings at the northern lake stations indicated mesotrophic or eutrophic conditions, this was due to inflow of turbid runoff delivered by the Clark Fork and not by increased biological production. (Hoelscher *et al.* 1993).

6. **The targets are based on an area-weighted average.**
From the standpoint of nutrient cycling, the north and south areas of the lake are functionally distinct. The targets are protective of water quality throughout the open waters of the lake, and take into account differences between regional areas of the lake.

Four of the pelagic monitoring stations established for the Section 525 study were located at Bayview, Granite Point, Hope, and Contest Point (Woods 1991a). Area weighted values were based on surface area of lake segments as follows: segment 1 (Bayview and Granite), 70%; segment 2 (Hope and Contest Point), 30%. Using reported mean values for segment 1 and segment 2 from Woods, the average 1989 total phosphorus was 8.40 ug/l, and the 1990 value was 6.26 ug/l, with the average of these two years being 7.33 ug/l. Segments are delineated on the Pend Oreille Lake map, Attachment C.

Table 1. Area-weighted average calculations

Woods (1991)			
	Granite Segment 1 (70%)	Hope Segment 2 (30%)	Weighted Average
1989	8.1	9.1	8.40*
1990	5.9	7.1	6.26
Average	7.0	8.1	7.33

* e.g. (0.70 x 8.1) + (0.30 x 9.1) = 8.40

Further assumptions associated with development of the total phosphorus target are included in Attachment E, Pend Oreille Lake Total Phosphorus Targets.

7. **In-lake mixing of Clark Fork River inflow is an important factor, but is highly variable from year to year.**
Although mixing is an important factor, certain highly variable conditions make it difficult to predict how mixing will occur in the lake from year to year. The nutrient load/lake response model applied during the Section 525 studies was based on an annual nutrient budget and assumed that a major portion of phosphorus input from the Clark Fork River was routed through the northern segment of the lake and did not mix with the southern segment. This assumption was calibrated by in-lake tracking of the spring run-off plume from the Clark Fork River. Using a transmissometer to measure transparency, USGS tracked the plume as it moved across the northern segment and out through the Pend Oreille River; additionally the tracking indicated that the overflow plume was less dense than lake water and stayed on top as it moved through. The results of the tracking were verified by sampling of conductivity at Cabinet Gorge and Albeni Falls. Other factors contributing to year-to-year variability in mixing, and thus to management uncertainties, include: years of very large flows when the loading could move to the south segment and go into storage; very heavy snow years when the run-off plume is much colder and could mix more with the lake

as it moves through; or an extremely turbid run-off plume that could settle into the delta. (Woods, personal communication.)

8. **In addition to mixing, certain other important variables exist for which data cannot predict at this time the potential for impacts to the lake or to the targets.** These variables, which are the result of either (1) nutrient loading, or (2) lake expression of nutrient loading, or both, are:
   - -Introduced species (2)
   - -Food chain dynamics versus productivity (2)
   - -Hydrology (including water yield, water rights, dam operations) (1) (2)
   - -Lake internal dynamics (1) (2)
   - -Nutrient dynamics (upstream impoundments, and the lake itself) (1)
   - -Upstream management (Clark Fork VNRP, Flathead TMDL, new sources) (1)
   - -Meteorology (temperature, sunlight) (1) (2)
   - -Atmospheric deposition (1) (2)
   - -Ability to detect changes in the lake year-to-year (statistical challenge, sampling method) (2)

9. **The nutrient targets for Pend Oreille Lake are protective of lake water quality over the long term, while allowing for year-to-year variability.** Lake loading can be highly variable from year to year as a result of runoff and other controllable and uncontrollable factors. However, the lake's trophic status over the long term appears to be insensitive to small-to-moderate alterations in phosphorus and nitrogen inputs. The targets, therefore, accommodate short-term variations while affording long-term water quality protection for the open waters.

10. **The application of the targets within the State of Montana and the State of Idaho will be the responsibility of each of the states.** Although the sources of pollution may be different, it is assumed that Montana and Idaho have equal commitment and comparable ability to achieve and maintain their respective allocations.

B. Total Phosphorus

A simple mathematical model can be used to define the relation between annual total phosphorus loading and total phosphorus concentrations in the lake euphotic zone, the well-lighted portion of the water column where photosynthesis takes place. The model used for Pend Oreille Lake was originally developed by Vollenweider (1976). A conceptual representation of the expected relationship between phosphorus loading and in-lake concentration is further illustrated in a predictive graph (Hoelscher *et al*. 1993), Attachment F.

As stated earlier, loading of total phosphorus is likely related to hydrologic events as phosphorus is adsorbed to soil particles. Frenzel (1991a) reported precipitation at Sandpoint, Idaho in 1989 was the same as the 1913-1988 average while the Clark Fork

River discharge was slightly less (93%) than the average for 1928-1988. He presumed near average conditions also likely existed for ungaged drainages surrounding the lake. In 1990, precipitation was 105% and the river discharge was 116% of the long-term averages. Frenzel (1991b) estimated the total phosphorus load to Pend Oreille Lake was 292,000 kg in 1989 with the Clark Fork River contributing 80% and 361,000 kg in 1990 with the river contributing 83% of the total phosphorus load. Therefore, these data likely represent usual hydrologic and loading conditions. Temporal variability in the annual total phosphorus load to Pend Oreille Lake was 21% as measured by the relative percent difference (APHA 1998). Frenzel (1991b) estimated overall error, inclusive of errors in the hydrologic budget and estimated errors in the collection and analysis of the nutrient samples, was about 16% of the total load to Pend Oreille Lake and River upstream from Albeni Falls Dam. Land & Water (1999) estimated the accuracy for estimates of mean annual phosphorus concentration in the Clark Fork River to be within 30% based on a sample size of 18 per year.

Woods (1991a) reported lakewide total phosphorus concentrations of 8.4ug/l in 1989 and 6.2 ug/l in 1990. Relative percent difference, inclusive of temporal variability—comprised of annual loading differences as well as in-lake nutrient cycling—and measurement error, was 32%. Measurement error was estimated at 7.2%. Total phosphorus concentrations did vary spatially with higher concentrations in the northern end of the lake in closer proximity to the Clark Fork River inflow. Separation of Pend Oreille Lake into basins based on these data is not recommended because of the uncertainty of the Clark Fork River inflow annual mixing characteristics, the overwhelming dominance of the southern lake basin volume of water, and any real basin differences in total phosphorus concentration would likely be eclipsed by temporal variability.

The average total phosphorus load (328,651 kg) to Pend Oreille Lake accurately predicted within measurement error the observed average area-weighted euphotic zone lake total phosphorus concentration (7.3 ug/l). These data are realistic as the lake as a whole has a multiple year hydraulic residence time. Combining the 1989 and 1990 hydrologic data accounted for about 85% of the water volume in Pend Oreille Lake.

Many researchers have presented trophic state classification systems. The system described by Ryding and Rast (1989) was used for these analyses. Their classification system identified trophic state boundaries for oligotrophic waters as four micrograms per liter total phosphorus and ten micrograms per liter for mesotrophic waters. For any waterbody, there is a gradation in water quality along these boundaries. Sonzogni *et al.* (1976) estimated the phosphorus residence time at about three times the hydraulic residence time. This is about ten years for Pend Oreille Lake. Assuming total phosphorus loads in the mesotrophic range occurring once in a ten year period may provide for undesirable water quality conditions, a gradation for mesotrophic characteristics was set at plus or minus ten percent of the value reported by Ryding and Rast (1989).

An euphotic total phosphorus concentration of 7.3 ug/l is recommended as a target for Pend Oreille Lake. This value should either be derived from a south-lake sampling location, due to the dominance of lake volume, or better from an area-weighted average of a south-lake and north-lake location. The latter would better represent any significant changes in the major inflow, the Clark Fork River. Assuming a combined temporal variability and measurement error of 30%, euphotic total phosphorus concentrations representative of mesotrophic conditions should be detectable.

An annual total phosphorus load of 259,500 kg/yr is recommended as a target for the Clark Fork River at the Montana-Idaho state line. This value was derived by taking the average annual total phosphorus load for the 1989-90 period reported by Frenzel (1991b). An annual total phosphorus load of 69,151 kg/yr is recommended for local sources in Idaho based on the nutrient budget developed by Frenzel. The 1989-90 record is considered to be representative based on basin water yield and precipitation, which was near normal for the period.

Independent confirmation of USGS 1989-1990 total phosphorus load estimates for the Clark Fork is provided by MDEQ monitoring data. Data collected from 1984-1999 were used to estimate 1989-1990 total phosphorus loads using the FLUX model. The FLUX algorithm (Method 6) employed a regression model using all data for the period of record applied to individual daily flows to estimate annual loads. Using MDEQ data (n=166), the estimated loads for 1989-1990 were 216,400 kg and 273,904 kg, respectively (Land & Water 2000). The average of these values is 245,152 kg, which corresponds to a relative percent difference of 5.7% compared with USGS value of 259,500 kg (Frenzel 1991b). This relative difference is within measurement and estimation error for the load values, and does not represent a statistically significant difference.

The USGS value of 259,500 kg is supported by MDEQ data, and is recommended as the target value to maintain consistency with the calibrated lake model (Woods 1991b) that forms the basis for lakewide total phosphorus concentrations.

C. Total Nitrogen

Because historical data did not show strong evidence for support of a nitrogen target for the lake's open water, the Technical Team enlisted the assistance of Dr. C. Michael Falter (University of Idaho) to conduct a literature review and recommend an approach to nitrogen for Pend Oreille Lake. The results of Dr. Falter's findings and conclusions (Nitrogen vs. Phosphorus Limitation in Pend Oreille Lake Open Water) are included in Attachment D and can be summarized as follows:

- Although nitrogen limitation has occasionally been recognized in oligotrophic systems, nitrogen limitation is generally associated with eutrophic waters.
- Nitrogen limitation is more likely to occur in aquatic environments where nitrogen loss through de-nitrification is common, such as in shallow waters. Because the lake's photic zone is far removed from sediment influence and its hypolimnion is oxygen-rich, Pend Oreille Lake would be expected to show little nitrogen limitation.

This suggests that nitrogen limitation should not be a significant issue in the lake, especially in its central and southern basins.

- Based on existing data, the lake appears to be primarily phosphorus-limited with occasional nitrogen limitation in late summer in the north lake. Mid- and south-lake regions show little or no nitrogen limitation.
- The ratio of total nitrogen to total phosphorus (TN:TP) serves as an indicator of a waterbody's nutrient balance and the potential for algae growth. Low TN:TP ratios are common in eutrophic lakes and blue-green algae blooms are rare when the TN:TP ratio is higher than 29:1. Algal blooms are more likely at low ratios.
- A TN:TP ratio greater than 15:1 indicates phosphorus limitation.
- During the 525 studies, TN:TP ratios in the lake's euphotic zone averaged 18:1 throughout the lake.

Based on Falter's findings, the Technical Team agreed that a nitrogen target is not justified at this time. However, because nitrogen-to-phosphorus ratios are an important indicator of potential changes to water quality, a TN:TP ratio of 15:1 is recommended as the desirable lower limit to avoid the occurrence of algal blooms in Pend Oreille Lake.

In-lake monitoring of the TN:TP ratio is recommended and an observed ratio of 15:1 or lower would serve as a trigger for reconsideration of setting a target for nitrogen.

D. Monitoring Plan Scope of Work

Introduction

A monitoring program must be in place to evaluate if the concentration and loading targets are being met and if those targets are effective in protecting the lake's water quality. In order to develop such a program, the Technical Team considered various scenarios of target exceedances and the subsequent management actions that might follow each of these scenarios. The scenarios included **episodic** (one year above the targets,) **short term** (three consecutive years above the targets) and **long term** (a ten-year average greater than the targets.) This review led the team to the following conclusions:

1. Recognizing that annual nutrient loading is inherently variable due to natural factors, periodic short-term exceedances of the loading targets may occur. However, the lake's buffering capacity has been adequate to accommodate natural variability (see discussion, Section 4). Therefore, a one-year exceedance of the targets would not trigger a management action. Of greater concern is the need to identify and assess the longer-term trend toward lake eutrophication as evidenced by increased loading.

2. A short-term exceedance of the targets (three consecutive years of total phosphorus load increases at the border that are above the targets by greater than 10%) should serve as a "red flag," triggering concern that a trend may be developing. Actions to be taken should include:
    - A review of the data to ensure confidence;

- A review of factors such as: annual runoff/water yield and ambient concentrations;
- A review of lake response data;
- An identification of causes (natural and human-induced) and sources (point and nonpoint; Montana and Idaho);
- A determination of error factor; and
- Consideration of development and implementation of a management strategy.

3 A long-term exceedance of the targets (a ten-year average total phosphorus concentration in the lake greater than 7.3 ug/l) will warrant the development of a management strategy to curb nutrient loading. Actions to be taken should include:
  - A review of data to ensure convincing evidence of a change in trend;
  - A review of causes (natural and human-induced) and sources (point and nonpoint; Montana and Idaho); and
  - Implementation of a management strategy

Because of the need to assess trends that are based on good science, the team recommends an annual monitoring program to build a record for the long-term. The products of the program will be an annual status report, an assessment of time trends, and an analysis of the associated causes. The objective of the program will be to detect real trends early enough so that appropriate and effective actions can be taken to protect Pend Oreille Lake water quality. Data collected during the monitoring program may potentially suggest re-definition of long-term targets and trends to protect the lake.

Monitoring Goals and Objectives

The purpose of monitoring is to generate reliable information on water quality trends and status for watershed managers. Analysis of approximately 10 years of historical nutrient data for the Clark Fork watershed provided statistical design criteria for the load monitoring program at Cabinet Gorge (Land & Water 1995).

Three principle water quality monitoring objectives are defined for Pend Oreille Lake. These include 1) estimation of annual total phosphorus loads to Pend Oreille Lake from the Clark Fork River, 2) assessment of open water, lake-wide average total phosphorus concentrations in the euphotic zone and 3) assessment of trends in Pend Oreille Lake trophic status (Carlson Index). These objectives will be coordinated with the existing Clark Fork-Pend Oreille water quality monitoring program. A future objective will be developed to evaluate attainment of phosphorus loading targets for the Idaho portion of the watershed, which will be based on a nutrient management strategy for the lake.

For the purposes of determining achievement of the states' respective loading targets, it is recommended that Montana evaluate sampling data from the Clark Fork River at the border (Cabinet Gorge) and that Idaho develop and implement a program—as noted above—that will quantify nutrient loading from point, nonpoint and atmospheric sources within the Idaho portion of the watershed. Individual management and monitoring goals are outlined with appropriate statistical criteria in the following sections.

1.1.1 Clark Fork River, Total Phosphorus Load Targets (Montana Sources)

MANAGEMENT GOAL: Maintain Montana phosphorus loading targets
MONITORING GOAL: Compare annual total phosphorus loads to target
DEFINITION OF TARGET: 259,500 kg annual load of total phosphorus
STATISTICAL METHODOLOGY: Shewhart-Cusum Control Chart
STATISTICAL HYPOTHESIS: Ho: Estimated load within control limits, short/long term
Ha: Estimated load outside control limits, short/long term
DATA ANALYSIS RESULT: Conclusions regarding achievement of targets
INFORMATION PRODUCT: Management goal met when estimated load is within control chart baseline values

1.1.2 Pend Oreille Lake, Total Phosphorus Concentration

MANAGEMENT GOAL: Maintain pelagic water quality
MONITORING GOAL: Evaluate departures from baseline phosphorus concentration
DEFINITION OF WATER QUALITY: Total phosphorus, euphotic zone, area-weighted lake annual average
DEFINITION OF TARGET: Mean concentration equal to or less than baseline of 7.3 ug/l
STATISTICAL METHODOLOGY: Two sample t-test, or Mann-Kendall if non-normal distribution, 90% C.L.
STATISTICAL HYPOTHESIS: Ho: No statistical difference from baseline exists
Ha: Statistical departure from baseline exists
DATA ANALYSIS RESULT: Conclusions regarding departure of annual mean concentration from baseline conditions
INFORMATION PRODUCT: Management goal met if no statistically significant difference from baseline value exists

1.1.3 Pend Oreille Lake, Trophic Status

MANAGEMENT GOAL: Maintain pelagic water quality
MONITORING GOAL: Detect significant trends in trophic status
DEFINITION OF WATER QUALITY: Carlson index (Total P, Secchi Depth, Chl a).
DEFINITION OF TREND: Presence of statistically significant trend in 10 year period
STATISTICAL METHODOLOGY: Seasonal Kendall with Sen slope estimate
STATISTICAL HYPOTHESIS: Ho: No trend exists
Ha: Trend exists
DATA ANALYSIS RESULT: Conclusions regarding presence of trends
Provide estimate of trend magnitude
INFORMATION PRODUCT: Management goal met when no trend exists, or indicates improvement

1.1.4 Pend Oreille Lake, Total Phosphorus Load Targets (Idaho Sources)

MANAGEMENT GOAL: Maintain Idaho phosphorus loading targets
MONITORING GOAL: Compare annual total phosphorus loads to target
DEFINITION OF TARGET: 69,151 kg annual load of total phosphorus
STATISTICAL METHODOLOGY*:
STATISTICAL HYPOTHESIS*:
DATA ANALYSIS RESULT*:
INFORMATION PRODUCT*:

*To be developed upon completion of a lake nutrient management strategy.

Monitoring Stations

Monitoring stations are located at sites of historical USGS data collection, and are representative of mid lake and north lake zones.

Table 2. Monitoring Locations

Site	Latitude	Longitude	Area Represented
Granite Point (2.5 mi SW) USGS Station 2000257	48-04’56”	116-28’33”	South-Central Lake, 70% area; 232.2 km^2
Hope (1 mile W) USGS Station 2000259	48-15’00”	116-20’30”	North Lake, 30% area; 99.9 km^2

Monitoring Parameters

Water samples for total phosphorus, total nitrogen, soluble reactive phosphorus and total soluble inorganic nitrogen are collected from the euphotic zone (2.5x Secchi depth). Nitrogen variables will be monitored to evaluate N:P ratios (see discussion, Pages 16-17.) If resources allow, it is recommended that soluble phosphorus and nitrogen also be analyzed to provide a more robust data set that may help with identification of nutrient sources. Samples will be taken using a 1000 ml Kemmerer sampler, and depth integrated from the euphotic zone. Chlorophyll-*a* samples will be collected from the same two locations. Field parameters will also include Secchi depth measured at Hope, Granite and Bayview. Detailed sampling methods will be contained in a sampling and analysis plan currently being prepared by Land & Water and to be approved by Montana and Idaho.

Table 3. Sample volumes, containers, preservation and holding times for lake nutrient samples

Analyte	Sample Volume	Container	Preservation	Holding Time
Total P and N	125 ml	polyethylene	add H_2SO_4 to pH<2, cool to <4°C	28 days
Total Soluble inorganic N[4] (NO_2+NO_3+NH_4)	125 ml	polyethylene	filter, add H_2SO_4 to pH<2, cool to <4°C	28 days
Soluble Reactive Phosphorus[1]	125 ml	polyethylene	filter, cool to <4°C	48 hours
Chlorophyll-*a*	1000 ml	amber polyethylene	Filter, freeze	7 days

Monitoring and Assessment Program Costs

Funding for the following monitoring program elements will need to be covered:

- Monitoring for the above parameters at two stations (Hope and Granite);
- Applicable data from the Council's existing Clark Fork-Pend Oreille monitoring program;
- Trend analyses and reporting; and
- Source loading analysis from Idaho

E. Targets, Loading, Allocation and Monitoring Summary

Based on a review of water quality data, the Technical Team concluded that water quality in the lake's *open water* has not changed significantly since the 1950's. The team therefore concurred with the conclusion of the Section 525 study that maintenance of current water quality is an appropriate goal. To set an in-lake target that would maintain open lake water quality, the team utilized data from the Section 525 studies and MDEQ's long-term monitoring record, along with modeling methods for calculating the correlation between oligotrophic and mesotrophic lake conditions. This target is 7.3 ug/l total phosphorus to protect and maintain open lake water quality.

To meet the in-lake concentration target of 7.3 ug/l total phosphorus, the team set a target for total loading to Pend Oreille Lake of 328,651 kg/yr total phosphorus. To address contributions to the lake's open water from both the Clark Fork River and local sources, the total load is allocated as follows: 259,500 kg/yr total phosphorus from Montana

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[4] Optional monitoring variables

(Clark Fork River at Montana/Idaho state line) and 69,151 kg/yr total phosphorus from the Pend Oreille Lake watershed in Idaho.

Based on existing data, the lake appears to be primarily phosphorus limited, therefore the in-lake target and allocations focus on total phosphorus. However, the in-lake nitrogen-to-phosphorus (N:P) ratio will be monitored. An observed N:P ratio of 15:1 or lower may indicate a shift toward nitrogen limitation in the lake and will serve as a trigger to initiate the setting of a target for total nitrogen.

A water quality monitoring program is essential to determine if the goal of maintaining open lake water quality is being met. The team has developed a program that includes sampling design to evaluate annual phosphorus loading to Pend Oreille Lake from the Clark Fork River and in-lake concentrations of total phosphorus. Monitoring will also provide the means to detect long-term trends in trophic status of the lake, since it is critical to detect real trends early enough so that appropriate and effective actions can be taken to protect Pend Oreille Lake water quality.

V. Attachments

- Attachment A: Glossary
- Attachment B: Reference List
- Attachment C: Map of Pend Oreille Lake
- Attachment D: Nitrogen vs. Phosphorus Limitation in Pend Oreille Lake Open Water, C. M. Falter
- Attachment E: Pend Oreille Lake Total Phosphorus Targets, B. Anderson and B. Hoelscher
- Attachment F: Predictive Graph

Attachment A: Glossary

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algae Small aquatic plants lacking stems, roots, or leaves which occur as single cells, colonies, or filaments.

algal bloom Rapid, even explosive growth of algae on the surface of lakes, streams, or ponds; stimulated by nutrient enrichment.

beneficial use Any of the various uses which may be made of the water, including, but not limited to, domestic water supplies, industrial and agricultural water supplies, recreation in and on the water, wildlife habitat, and aesthetics. Any use may not lower the ambient water quality.

benthic The bottom of lakes, streams or ponds.

chlorophyll a The dominant green, photosynthetic pigment in plants; a measure of aquatic plant production.

cultural eutrophication An accelerated rate of lake aging induced by human sources of nutrients, sediment, and organic matter.

discharge In the simplest form, discharge means outflow of water. The use of this term is not restricted as to course or location and it can be used to describe the flow of water from a pipe or from a drainage basin. Other words related to discharge are runoff, flow, and yield.

dissolved oxygen Molecular oxygen freely available in water and necessary for the respiration of aquatic life and the oxidation of organic materials.

drainage area The land area contributing runoff to a stream or other body of water, and generally defined in terms of acres, square miles, or square kilometers.

effluent The sewage or industrial liquid waste which is released into natural waters by sewage treatment plants, industry, or septic tanks.

erosion The wearing away of the landscape by water, wind, ice, or gravity to smaller particles, usually sediment.

euphotic zone The depth to which one percent of incident surface light penetrates; the lighted zone of a waterbody.

eutrophic Literally, "nutrient rich." Generally refers to a fertile, productive body of water. Contrasts with oligotrophic.

eutrophication The natural process by which lakes and ponds become enriched with dissolved nutrients, resulting in increased growth of algae and other microscopic plants and reduced water clarity.

flow The rate of water discharged past a point expressed in water volume per unit time.

hydraulic residence time The amount of time it would take to completely fill a lake if it were empty; equals lake volume/water inflow.

hypolimnion The lowermost, non-circulating layer of cold water in a thermally stratified lake; usually deficient in oxygen.

limnology The branch of science pertaining to the study of the physical, chemical, biological, and ecological aspects of fresh water; the structure and dynamics of ponds, lakes, streams and wetlands.

littoral zone That portion of a lake or pond extending from the shoreline lakeward to the greatest depth occupied by rooted aquatic plants.

load The amount of substance, usually nutrients or sediment, discharged past a point; expressed in weight per unit time.

macrophyte The larger, non-microscopic aquatic plants found in shallow areas of lakes and streams.

mean depth A lake's volume divided by its surface area.

mesotrophic Literally, "moderate nutrients." Generally refers to a moderately fertile body of water.

model A simulation by descriptive, statistical or other means, of a process otherwise difficult or impossible to observe directly.

nitrogen An essential nutrient for aquatic organisms, comprising 80% of the earth's atmosphere.

nonpoint source pollution Pollution discharged over a wide land area, not from one specific location.

nutrient loading The addition of nutrients, usually nitrogen or phosphorus, to a water body (often expressed as g/m^2 of lake surface area per year) . The majority of nutrient loading in a lake usually comes from its tributaries.

nutrients Elements or compounds essential to life, including but not limited to oxygen, carbon, nitrogen, and phosphorus.

oligotrophic Literally, "nutrient poor." Generally refers to an infertile, unproductive body of water. Contrasts with eutrophic.

pelagic In the open waters of a lake; removed from shoreline effects.

pelagic zone The open area of a lake from the littoral zone to the center of the lake.

phosphorus An essential nutrient for aquatic organisms derived from weathered rock and human sources.

phytoplankton Usually microscopic aquatic plants (sometimes consisting of only a cell).

point source pollution Pollutants discharged from any identifiable point, including pipes, ditches, channels, sewers, tunnels, and containers of various types.

pollution Any alteration in the character or quality of the environment which renders it unfit or less suited for beneficial uses.

primary production The synthesis of organic compounds by green plants in the presence of elements (e.g. nitrogen, phosphorus) and light energy.

secchi depth The mean depth at which a black and white disk 20 centimeters in diameter is no longer visible from the water surface; a measure of water transparency.

sediment Fragmented organic and inorganic material derived from the weathering of soil, alluvial, and rock materials removed by erosion and transported by water, wind, ice, and gravity.

sewage The water-carried human and animal waste from residences, buildings, industrial establishments, or other places, together with groundwater infiltration and surface water.

stormwater runoff Surface water runoff, usually associated with urban development, which carries both natural and human-caused pollutants. Stormwater runoff can be conveyed to lakes, ponds, and streams either through point or nonpoint sources.

suspended sediment Solids, either organic or inorganic, found in a body of water, which can be removed by filtration. The origin of suspended matter may be man-made wastes or natural sources such as silt.

trophic status Referring to the nourishment status of a water body, e.g. oligotrophic, eutrophic.

turbidity Cloudiness caused by the presence of suspended solids, such as clay, silt, and microscopic organisms in the water; an indicator of water quality.

wastewater Treated or untreated sewage, industrial waste, or agricultural waste with such water as is present. Sometimes referred to as effluent.

water clarity The ability of water to transmit light; often reported as secchi depth.

water quality standard Legally mandated and enforceable maximum contaminant levels of chemical, physical, and biological parameters for water. These parameters are established for water used by municipalities, industries, agriculture, and recreation.

water quality A term used to describe the chemical, physical, and biological characteristics of water with respect to its suitability for a beneficial use.

water year The twelve month period from October 1 to September 30, and designated by the calendar year in which the water year ends.

watershed An area of land that contributes surface runoff to a given point in a drainage system.

Attachment B: Reference List

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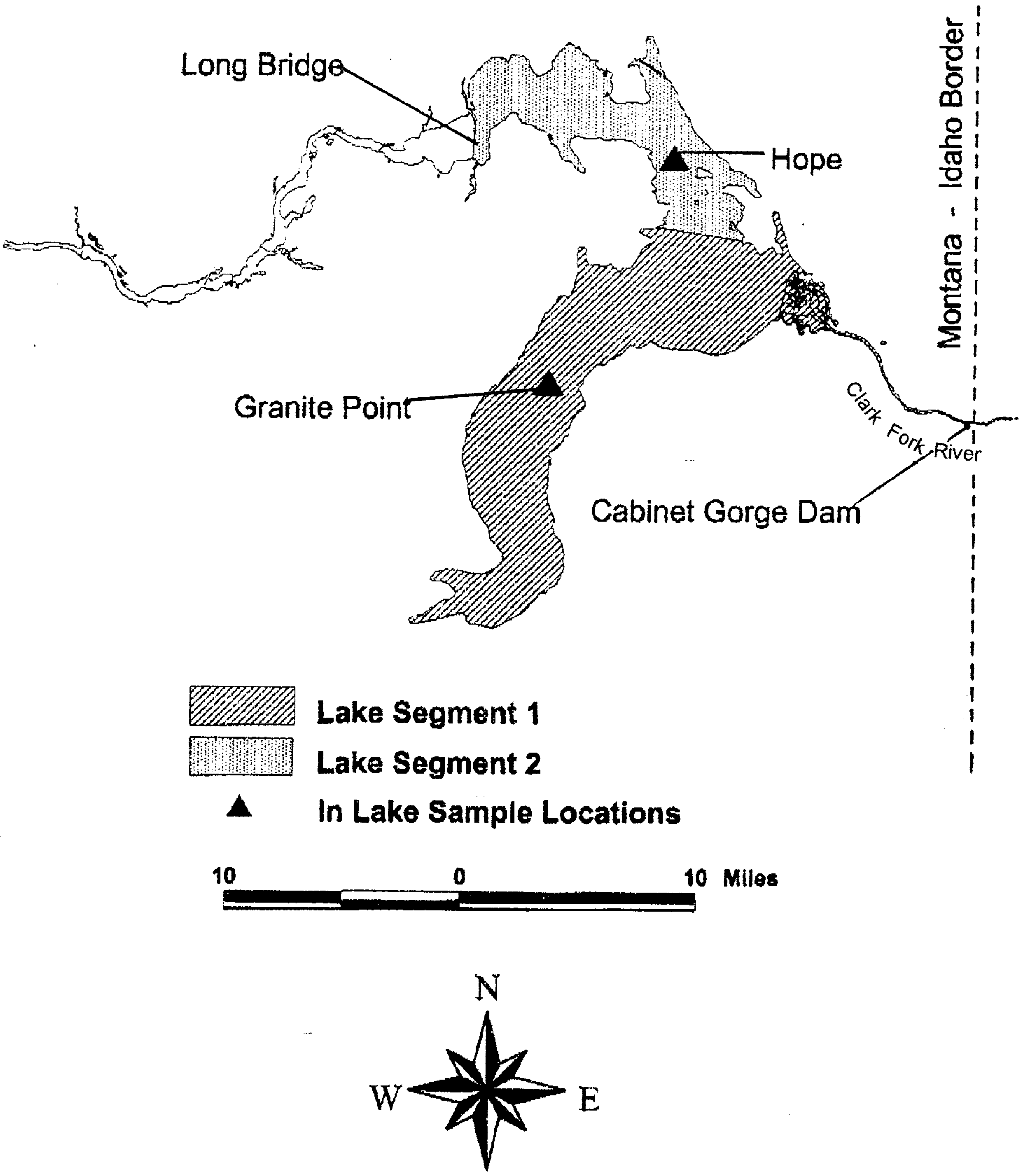
Attachment C: Pend Oreille Lake Map



Attachment D: Nitrogen *vs.* Phosphorus Limitation in Pend Oreille Lake Open Water

C. Michael Falter
April, 2000

The following summary comments address several questions in the on-going discussion of nutrient control in Pend Oreille Lake:

- What form(s) of nitrogen and phosphorus should be considered?
- What is a desirable TN:TP ratio target in Pend Oreille Lake?
- Should a nitrogen TMDL be set for Pend Oreille Lake?

The following summary comments are based on a review of papers listed in the following References section:

- Dissolved N and P, although directly utilized by algae, show little relationship to measured algae standing crop and growth, and consequently, little relationship to nutrient limitation in large rivers and lakes. Although TDN and TDP concentrations in flowing waters are better indicators of instantaneous nutrient supply, TN and TP are more indicative of the nutrients that are <u>ultimately</u> biologically available (over days and weeks) for algal growth than are TDN and TDP. The relationship between dissolved N and P with nutrient limitation can, however, be strong in small turbulent streams.
- TN and TP show the best relationships with algae growth and limitation on a worldwide basis as well as in the Clark Fork drainage (Smith 1982; Hecky and Kilham 1988). Although ideally, only biologically available N and P should be considered for short-term relationship to algal growth, TN and TP relate better to seasonal and lakewide productivity (USEPA 1998 b and USEPA 1998c).
- The TN:TP ratio probably overestimates short-term biologically available forms and the TDN:TDP likely under estimates them. Nordin (1985) felt that in streams, N:P ratios should be based on soluble reactive phosphorus and dissolved inorganic nitrogen (nitrate + ammonia). In practice, however, there is very poor correlation between DIN or DIP levels and algae response. This is because: 1) Algae activity may sharply reduce DIN and DIP and; 2) Luxury uptake blurs the relationship between algae need and water concentrations (USEPA 1998b).
- TN:TP ratios $\leq$ 5:1 indicate nitrogen limitation;

  TN:TP ratios between 5 - 15:1 indicate co-nitrogen & phosphorus limitation;

  TN:TP ratios $\geq$ 15:1 indicate phosphorus limitation.

Low TN:TP ratios are more common in eutrophic lakes, a pattern generally observed over many lake studies (Smith 1982; Smith 1983; Stockner and Shortreed 1988). Smith (1983) reviewed 17 temperate lakes worldwide and reported a dramatic tendency for blue-green algae blooms to occur when epilimnetic TN:TP ratios fell below 29:1, and that blue-green algae were rare when the TN:TP ratio exceeded 29:1.

- Straskaba (1980) argued that the slope of Chl *a*-TP relationships changed systematically depending on the TP concentration, and that the relationship nearly disappeared at either very high nitrogen or phosphorus concentrations. More productive lakes often have low TN:TP ratios (Straskaba (1980; Smith 1980) and it has been observed that the slope of Chl *a*-TP relationships in lakes varies between N-deficient lakes (low TN:TP ratios) and P-deficient lakes (high TN:TP ratios). Prairie et al. (1989) concluded that both TN and TP correlated equally well with chlorophyll *a* over the whole TN:TP range (observed over a data set of 133 temperate lakes). Lakes in a central range of TN:TP (between 23:1 and 28:1) showed greatest response of chlorophyll *a* to nutrient concentration ranges.
- Through the mid- to late '80's, mean TN:TP ratios in Pend Oreille Lake were:

North-lake euphotic zone	-	16.0
North-lake deep zone	-	18.8
Mid-lake euphotic zone	-	28.2
Mid-lake deep zone	-	18.6
South-lake euphotic zone	-	31.3
South-lake deep zone	-	11.9

- 1989-90 TN:TP ratios in the euphotic zone averaged 18.0 throughout the lake.
- Deep zone TN:TP ratios are closer to N limitation, but the issue there (in the absence of light) is probably moot.
- North lake TN:TP ratios, more driven by the Clark Fork River, suggest borderline N-limitation in late summer.
  Mid- and south-lake TN:TP ratios indicate increasing phosphorus limitation with the longer retention times southward through the lake basin.
- Smith (1983) maintained that N removal resulting in low TN:TP ratios could favor blue-green algae and thus be counterproductive to eutrophication control.

  Stockner and Shortreed (1988) tested this theory *via* a fertilization experiment where an oligotrophic lake in Ontario was fertilized with phosphorus, driving down the TN:TP ratio to $\leq$ 15:1 and resulting in the development of nitrogen-fixing *Anabaena* blooms, heterotrophic bacterial and piccoplankton algal communities. After 2 years of fertilization, the blooms were controlled by bringing TN:TP to 35:1.

The authors concluded that the bloom development was a result of both high phosphorus and low nitrogen supply.

- Although nitrogen limitation has occasionally been recognized in oligotrophic limnetic systems (Lewis *et al.* 1984; Morris 1985; Suttle and Harrison 1988), N limitation is generally associated with eutrophic waters. Schindler (1975 and 1977) was among the earliest workers to demonstrate this theory, but the pattern has been consistently supported over a wide range of water bodies (Stockner and Shortreed 1988). Later investigations have detailed the patterns of TN:TP ratios and the occurrence of colonial Cyanophytes in blooming temperate lakes (McQueen and Lean 1987; Seale *et al.* 1987). A major reason is the ability of bluegreen algae to fix atmospheric nitrogen in situations of low available nitrogen in the aquatic environment (hence low TN:TP ratios). A number of studies (summarized by Suttle and Harrison (1988) have shown that N fixers are poor competitors for phosphorus, hence can be out-competed for available phosphorus when phosphorus is low (high TN:TP ratios). High TN:TP ratios therefore select against N-fixing cyanobacteria.
- For some time, it was assumed that nitrogen limitation of algal biomass seemed to be more common in subtropical and tropical lakes (Hecky *et al.* 1993). An extensive recent analysis of 420 temperate, tropical, and sub-tropical lakes (Mazumder and Havens 1998) rejected this theory and concluded that nitrogen does not explain a greater portion of Chl *a* variance in subtropical lakes compared with temperate lakes. The authors were able to show on that data set of lakes that Secchi transparency at given chlorophyll *a* and nutrient concentrations decreased from temperate to subtropical lakes, a result of abiotic turbidity and plankton size.
- As a phenomenon, N limitation is more likely to occur in aquatic environments where N loss through denitrification is more common. Such locations would be shallow water environments where proximity to oxygen-limited sediments where N denitrification is common *(i.e.* littoral areas) and littoral marine waters where reducing muds are the rule (Smith 1984 ; Paerl 1985 and 1988). By nature of a photic zone far removed from sediment influence and its oxygen-rich hypolimnion and sediment environments, Pend Oreille Lake would logically be expected to show little N-limitation. This reasoning alone would suggest that nitrogen-limitation should not be a significant issue in Pend Oreille Lake, especially in its central and southern basins.
- Nitrogen limitation is common in the Clark Fork River, especially in late summer. This is supported both by TN:TP ratios and experimental algal growth studies (Watson 1991; Lohman and Priscu 1992).
- USEPA's 1998 draft technical guidance document on nutrient criteria in streams accepts that N limitation is more likely in streams than in lakes. Phosphorus removal mechanisms are more dominant in lakes than in streams. The extreme

morphometric oligotrophy of POL would further suggest high probability of phosphorus loss with subsequent P limitation in the lake.

- Algal limiting nutrient assays in POL through the fall, 1984 indicated primary P limitation with secondary limitation by N at all sites (Woods 1991).
  Algal limiting nutrient assays in POL through the summer-fall, 1986 indicated primary P limitation and secondary N limitation in the north- and mid-lake but exclusive P limitation in the south lake.
- POL seems to be primarily P-limited with occasional N-limitation in late summer in the north lake. Mid- and south-lake regions of the lake show little or no N limitation.
- The fact that the Clark Fork River is often N-limited probably has little bearing on the limiting factor situation in most of POL south or, or very far west of the Clark Fork River influence during summer/fall months.
- The often observed enrichment of nearshore algal and aquatic macrophyte communities in large lakes relative to pelagic waters is usually attributed to nutrient enrichment from near-lake shoreline activities in the watershed. Certainly, this has been the explanation given with Pend Oreille Lake (Woods 1991 a and 1991 b; Kann and Falter 1989). An additional factor undoubtedly contributing to nearshore productivity in Pend Oreille Lake is seiche-induced mixing. Ostrovsky et al. (1996) describe the sediment-water exchange from the high-velocity water movements across nearshore sediments when an internal seiche wave alternately moves shoreward, then lakeward repeatedly during the period of the internal seiche (Lake Kinneret, Israel). Rieman and Falter (1976) described similar, but far greater magnitude internal waves in Pend Oreille Lake which may result in 20 m vertical displacement of water. Certainly such injection of metalimnetic water into the littoral zone can represent a significant enhancement of available nutrients to nearshore communities during stratification. The specific mechanisms are seiche-induced turbulence at the sediment-water interface with sediment suspension and nutrient mixing into the water column as well as cross iso-pycnal mixing when the lake is stratified.
- Control of nutrients alone cannot be expected to totally control algal growth. In addition to nutrients, grazers, grazer-nutrient interactions, lake morphometry, thermal pattern, and light regimes have all been shown to be important in determining phytoplankton biomass in lakes (reviewed by Smith 1990; Mazumder 1994; and Mazumder and Havens 1998). Mazumder (1994) developed models that accounted for these complex interactions in affecting TP-Chlorophyll *a* relationships in temperate lakes. In that work, the author was able to classify temperate lakes by the presence or absence of dense populations of large-bodied (> 1 mm length) *Daphnia* and to develop robust chlorophyll predictive models based on nutrients, grazer communities, and thermal regimes.

CONCLUSIONS:

1. TN and TP are the most useful forms of nitrogen and phosphorus to be followed by a management program in Pend Oreille Lake.
2. A nitrogen target is not justified at this time. However, a TN:TP ratio range of 15:1 is a desirable lower limit to avoid the occurrence of algal blooms in Pend Oreille Lake. Algal blooms are more likely at low ratios.

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Attachment E: Pend Oreille Lake Total Phosphorus Targets

Bruce Anderson/Brian Hoelscher
December 1, 2000

A number of technical issues and assumptions should be considered when reviewing total phosphorus targets for Pend Oreille Lake.

Woods (1991b) Pend Oreille Lake model was calibrated by lake segment, and provided a lakewide average concentration. The measured mean segment concentrations from 2 modeled segments in 1989 and 1990 were averaged to obtain an area weighted lakewide target for the lake in the Technical Guidance document.

The Technical Guidance assumes area weighted concentrations from selected "South" and "North" euphotic zone monitoring stations will accurately represent baseline in-lake concentrations derived by averaging segment data Woods 1991b. The North Station will be Hope, and the south station will be Granite point.

Data from only two years of pelagic monitoring was available, and model calibration based on 1989 data to predict 1990 lake segment concentrations had significant % error by segment and year (Woods 1991b).

Lakewide area average concentrations may not necessarily correlate with Clark Fork loading for individual years. Since only two years of paired lake/river data exist for total P, the strength of this correlation is unknown. The expected lake response to influent Clark Fork loads has been modeled, but not measured with a long term data set to verify lake response, sensitivity of lakewide averages to influent loading, etc.

Lakewide area average concentration will be preferentially weighted to the more isolated (relative to the Clark Fork) main body and southern portion of the lake. This lakewide average will be buffered from Clark Fork influence to some extent due to limited river/lake mixing characteristics in the southern lake area.

Aerial deposition of total P has not been measured directly, and the extent to which this may influence lakewide average annual or long term concentrations is uncertain. The selection of lakewide average as a target (as opposed to North segment only) potentially increases the relative influence of aerial deposition as a factor in lake target values.

Significant seasonal and annual variation is present in euphotic zone total P concentration, and monitoring results may be expected to vary from the proposed target due to these and other factors. The proposed stations/monitoring program is intended to be representative and comparable to Woods 1989-1990 data collection effort, however, review of target values may be necessary as paired lake and river data emerges.

Attachment F: Predictive Graph

Sensitivity of Pend Oreille Lake, total phosphorus concentration to total phosphorus load (Hoelscher *et al.* 1993). Graph illustrates increase in nutrient load that would move the lake closer to a more productive (nutrient rich) state.