Phosphorus removal alternatives at the Missoula Wastewater Treatment Plant

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Phosphorus Removal Alternatives At The Missoula Wastewater Treatment Plant

By

Christopher Matthew Cerquone

B.S., State University of New York at Cortland, 1984

Presented in partial fulfillment of the requirements for the degree of Master of Science University of Montana 1988

Approved by

[Signature]
Chair

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Dean, Graduate School

Date June 2, 1988
The Clark Fork River/Lake Pend Oreille ecosystem is threatened. Signs of accelerated eutrophication have been reported in Lake Pend Oreille and the Clark Fork River. According to the Montana Water Quality Bureau, phosphorus probably is the primary limiting nutrient for algal and plant growth in the Clark Fork Basin. Controlling phosphorus loading into the basin may improve water quality.

The Missoula Wastewater Treatment Plant (MWTP) is one of the largest sources of phosphorus in the basin. Six percent of all the phosphorus reaching Lake Pend Oreille is believed to come from the MWTP. Studies done by the Montana Department of Environmental Sciences and others show that the MWTP effluent increases algal productivity in the Clark Fork River.

There are several options the City of Missoula can follow to reduce phosphorus loading from the MWTP. Current operational practices can be modified to enhance phosphorus removal. Adopting a phosphate detergent ban might reduce the plant's phosphorus loading by 25%. Phosphorus can be chemically removed to an effluent total phosphorus level of 1.0 mg/l for approximately 1.2 cents per capita per day. Likewise, phosphorus can be removed biochemically for only 0.6 cents per capita per day. If phosphorus is removed chemically, more sludge will be produced, possibly exceeding the sewage plant's anaerobic digester capacity. Sludge metals concentration will also increase, but soils where sludge is applied should not be significantly affected. The biochemical process would pose no significant threat to the plant's treatment operations or the environment. A land application system may be used to reduce phosphorus loading from sewage treatment plants. Land application systems can adequately protect ground water and soils if properly designed and managed. At this time it is unknown whether a land application system can be used to treat the MWTP effluent. Soils around Missoula are known to provide poor filtering capacity. A Rapid Infiltration land application system used previously to treat wastes at the Frenchtown pulp mill ceased to work effectively and was abandoned.
Acknowledgments

I would like to thank:

Vicki Watson - for her continual support and willingness to help throughout this project and graduate school.

Peter Nielsen - for his direction and enthusiasm.

Ron Erickson and Peter Koehn - for making me remember no project should be analyzed on economics alone.

Tim Hunter, Gail Miller, Joe Aldegarie, and Scott Anderson - for making a very nonsexy topic like sewage treatment bearable and understandable.

Sandie McQuillan - for being patient when I needed computer time and advice.

The EVST Department - for being what it is; don't ever change.

And last Robin, my fiancee, and my best friend - for the patience, love, criticism, and support I needed the last two years. We did it Robo.
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INTRODUCTION

There is a jar full of water in front of me. The jar contains effluent from the Missoula Wastewater Treatment Plant. The water is clear, odorless, almost drinkable. I shake the jar and watch as small suspended particles float slowly to the bottom, like airborne dust filtering downward in a beam of sunlight. I wonder how something that looks so harmless could be the subject of such heated debate concerning the apparent eutrophication problem in the Clark Fork River Basin. I must remind myself that the cause of cultural eutrophication is thought to be nutrients (phosphorus and nitrogen) -- invisible, colorless, odorless constituents of the effluent.

Eutrophication - What is it?

Eutrophication is the natural aging process of in-land surface waters. Sediments and nutrients are washed down from surrounding lands, and lakes and pools are eventually choked with aquatic plants and sediments. Like people, no two lakes age at the same rate. Climate, soils, nutrient loading, aquatic plant species, water body morphometry, and many others factors combine to give a water body its own unique aging characteristics.

Normally, eutrophication is a slow process, taking thousands of years. Man's activities can accelerate the eutrophication process by adding more nutrients which
stimulate growth of algae and other plants. Whether it be from the activities of industry, logging, mining, or sewage treatment, surface water nutrient enrichment deteriorates water quality.

Nitrogen may be limiting for aquatic plant growth where there are high inputs of phosphorus to a water body from the activities of man, or in regions where nitrate and ammonium content in rain is low (Lee, Jones, and Rast, 1978). However, phosphorus is most often found to be the limiting nutrient for freshwater aquatic plant growth. In general, the more phosphorus entering a water body the greater the risk of water quality degradation. Water bodies are often described by aquatic scientists as rich (eutrophic), relatively sterile (oligotrophic), or intermediate (mesotrophic). Phosphorus loading to a water body appears to accelerate the natural progression towards richer conditions.

The Problem

The quality of the Clark Fork River and Lake Pend Oreille is threatened by accelerated eutrophication. Amounts of bacterial slime and algae growth on the shores of Lake Pend Oreille are comparable to those found recently in Lake Tahoe, a lake with well-documented nutrient problems (Mike Beckwith, personal communication). Residents around Lake Pend Oreille report recent increases in attached algae and floating scum, indicating
deterioration of water quality. Localized algal blooms and declining light penetration in Lake Pend Oreille have been reported (Woods, 1985). In 1983 Flathead Lake produced its first lakewide bloom of blue-green algae (Bahls, 1986). In the mainstem Clark Fork and its lower river reservoirs, heavy summer algal growths and reduced water clarity present not only an aesthetic problem, but a potential biological problem as well.

Studies in the mid-70s on Lake Pend Oreille suggested the lake was oligotrophic based on chlorophyll-a concentrations and daily integral primary productivity (Woods, et al., 1985). Since then, others have indicated the lake may be aging at faster than normal rate. Based on limited nutrient loading data, simple input/output models suggest that the lake varies from the oligotrophic-mesotrophic border to the mesotrophic-eutrophic border for phosphorus loading (Watson, et al., in review). The Montana Governor's Office reported that unless phosphorus loading in the basin is reduced, "we can expect irreversible changes in water quality, the loss of desirable fish species, and diminished recreational and property values" (Johnson and Knudson, 1985).

The Solution

Phosphorus inputs into the Clark Fork River Basin may have to be reduced to maintain the quality of the Clark Fork River and Lake Pend Oreille. Holding the line on
current phosphorus loading in the basin may not be enough to protect the quality of Lake Pend Oreille. Mike Falter, a professor at the University of Idaho studying algal relationships in Lake Pend Oreille, believes only a reduction in phosphorus loading will protect the lake from water quality deterioration (Mike Falter, personal communication).

Phosphorus source identification in the basin is the first step in restoring the pristine quality of the Clark Fork River/Lake Pend Oreille ecosystem. The Environmental Protection Agency (EPA) has provided funds to begin in-depth studies of nutrient and algal problems in the Clark Fork Basin, including an investigation of nuisance algal growths in the Clark Fork River and their potential control by limiting nutrient inputs from industry, sewage treatment plants, and forest and agricultural lands (Clark Fork Currents, 1987). At this time, no wastewater treatment facility is attempting to reduce nutrient loads along the mainstem Clark Fork, and only one facility, in Big Fork, Montana, is removing phosphorus from its wastewater.

Objectives Of Paper

The objectives of this paper are:

(1) to outline the current state of the Clark Fork River/Lake Pend Oreille system in reference to cultural eutrophication,

(2) to assess how the Missoula Wastewater
Treatment Plant is affecting eutrophication in the Clark Fork River Basin, and

(3) to present alternatives for phosphorus removal at the Missoula Wastewater Treatment Plant.

While nitrogen may also limit algal growth periodically in the Clark Fork River (Greene, et. al., 1986), I will only present phosphorus removal alternatives for the following reasons:

(1) factors such as nitrification, denitrification and fixation of nitrogen from the atmosphere by algae complicate nitrogen loads to water bodies, making control measures difficult.

(2) Phosphorus has been identified as the primary limiting nutrient for algal growth in the Clark Fork River/Lake Pend Oreille system (Greene, et. al., 1986; Woods, 1985).

(3) Phosphorus removal is both technically sound and economically feasible.

(4) Even in water bodies where nitrogen or some other factor limits algal growth, phosphorus load reduction can result in improved water quality.
This paper may prove useful as the City of Missoula and the Water Quality Bureau explore phosphorus removal alternatives at the Missoula Wastewater Treatment Plant (MWTP). Phosphorus removal alternatives presented here may be used for other sewage treatment plants of similar design in the basin and state.

CLARK FORK RIVER/LAKE PEND OREILLE ECOSYSTEM

Description Of The Clark Fork River Basin

The Clark Fork River/Lake Pend Oreille ecosystem is a highly valued resource. Municipalities use its waters for drinking and waste assimilation, farmers divert its flow for irrigation, recreationists tap its rapids and fishing holes, and some, living on the shores of Lake Pend Oreille and the banks of the Clark Fork, call it home.

The Clark Fork River Basin encompasses approximately 22,000 square miles upstream of Lake Pend Oreille, draining most of western Montana as well as a small portion of northern Idaho. The Clark Fork is Montana's largest river, annually discharging an average rate of 22,380 cubic feet per second (Johnson and Knudson, 1985). From its origin at the foot of the continental divide, the Clark Fork River flows north and west to Lake Pend Oreille (Figure 1). Upon leaving the lake, the river, now named Pend Oreille, flows northward to the border of British Columbia where it joins the Columbia River, in Washington on its surge to the
FIGURE 1
CLARK FORK RIVER/LAKE PEND OREILLE BASIN
Pacific. Along the way, the Clark Fork is joined by more than 150 tributaries. In Montana, the three largest are the Blackfoot, Bitterroot, and Flathead rivers, the latter contributing more than half the Clark Fork's total discharge at the Montana-Idaho border.

There are seven hydroelectric facilities within the Clark Fork River Basin. Besides creating electricity, the reservoirs provide recreational and agricultural benefits for the residents of the basin. Reservoirs also slow water flow trapping sediments and nutrients which may make them susceptible to eutrophication.

Lake Pend Oreille is the largest lake in Idaho and the sixteenth largest in the United States, excluding the five Great Lakes (Woods, et. al., 1985). The lake has an area of 148 square miles and a volume of 53.3 billion cubic meters. More than 90% of the volume reaching the lake comes from the Clark Fork River (Johnson and Knudson, 1985). The lake's quality is therefore highly dependent on the Clark Fork's quality.

Sources Of Phosphorus In The Clark Fork Basin

Phosphorus is found throughout much of the environment. Phosphorus is in soils, fertilizers, precipitation, volcanic rock, and human and animal wastes. Nonpoint sources of phosphorus may enter surface waters in the basin from wet and dry atmospheric deposition, runoff from forest and agricultural lands, groundwater, and lake and reservoir
sediments. Phosphorus also enters basin surface waters from point sources such as effluents from industry and sewage treatment plants.

Nonpoint sources of phosphorus may make up the bulk of the total phosphorus load in the basin; however, a significant amount of the nonpoint source load is in a form not readily available for algal and plant growth. Nonpoint phosphorus entering surface waters is often in particulate form, and settles to the bottom of lakes and reservoirs. Under anoxic conditions at lake bottoms this particulate phosphorus may solubilize, thus becoming available. Nonpoint sources may contribute up to 75% of the total phosphorus load to Flathead Lake, Montana, but only 10% of the nonpoint phosphorus is bioavailable (MDHES, 1984). Nonpoint phosphorus loads in the Clark Fork River Basin may be comparable to those estimated in the Flathead drainage, but exact contributions are not known at this time.

By contrast, point sources of phosphorus are notorious for contributing significant amounts of bioavailable phosphorus, also known as orthophosphorous. In general, greater than 70% of the phosphorus load from wastewater treatment plants is in a bioavailable form (Vollenweinder, 1968). From 1985 to 1987, 82% of the phosphorus load from the MWTP was orthophosphorous (MDHES, 1988). There are currently 30 waste permitted discharges in the Clark Fork River Basin, twenty-five of which are wastewater treatment
facilities (Johnson and Knudson, 1985).

**Controlling Phosphorus Loading In The Basin**

If phosphorus reduction efforts are attempted in the Clark Fork River Basin, they should be directed toward those sources of phosphorus which cause the greatest increase in algal growth. To restore or maintain water quality in the Clark Fork River/Lake Pend Oreille system, reduction from the following sources should be considered:

1. wastewater treatment facilities,
2. septic system drainfields, and
3. forest and agricultural lands.

**Septic system drainfields**

Septic system drainfields can leach phosphorus into ground water supplies which may eventually reach surface waters. Septic systems 20 to 30 years old can contribute significant amounts of available phosphorus to surface waters, particularly in sandy soils (Kerr, 1977). In most soils there is enough clay, iron oxide, and aluminum oxide to adequately protect ground water, but sandy soils often lack enough phosphorus adsorption sites to immobilize phosphorus.

Phosphorus may be reaching the Clark Fork River from septic system drainfields in the Missoula Valley. Soils of low cation exchange capacity (CEC) commonly provide inadequate protection against contaminant mobility.
samples taken down-gradient from a septic drainfield near the Bitterroot River had an extremely low CEC of 2.7 meq/100g (Verhay, 1987). Ground water phosphorus concentrations were found to be above normal levels. Whether phosphorus from septic systems is reaching the Bitterroot is unknown at this time, but Kicklighter (1987) reported very low ambient river phosphorus concentrations. However, Kicklighter did find high concentrations of nitrogen in the Bitterroot.

Phosphorus can be removed from septic systems by adding alum or lime (Jones and Lee, 1979), and reduced by eliminating phosphorus in detergents. A complete analysis of a phosphorus detergent ban can be found in this paper under the section "phosphate detergent ban".

Forest and agricultural lands

Phosphorus does enter the Clark Fork River Basin from forest and agricultural land. The U.S. Forest Service is the largest landowner in the basin, and private timber companies own a substantial amount of land in the Blackfoot and Thompson River drainages. Most of the forests in the lower elevations have been harvested. Logging activities such as clear cutting reduce the infiltration capacity of soils and increase overland flow and erosion, thus carrying nutrients to surface waters. This is especially true on steep hillsides, where loggers in the basin are beginning to harvest trees (Johnson and Knudson, 1985).
Adherence to "best management practices" increases infiltration capacity and minimizes erosion. Far too often these practices are not followed. The private timber companies that log federal lands are seldom monitored. Until "best management practices" are more strictly followed, forest operations will contribute to phosphorus loading.

Agriculture in the basin is also a source of phosphorus. Farmers often add phosphate fertilizers to cropland in excess of what is needed by crops (N. Stark, personal communication). Heavy rains or over-irrigation practices can lead to increased concentrations of phosphorus in ground water supplies. Education is the key to reducing phosphorus loads from agricultural lands. Controlling phosphate fertilizer application and irrigation practices should reduce phosphorus loading to the Clark Fork River Basin.

Sewage treatment plants

In watersheds where a significant percentage of bioavailable phosphorus load comes from wastewater treatment facilities, controlling phosphorus loading from these point sources provides the best means of reducing the rate of accelerated eutrophication. Under the 1972 U.S.-Canadian Water Quality Agreement passed to control eutrophication in the Great Lakes, wastewater treatment plants are required to limit total phosphorus effluent
concentrations to 1.0 mg/l (Black, 1984). A 1.0 mg/l total phosphorus limit on all point sources was also recommended to control eutrophication in Flathead Lake, Montana (MDHES, 1984).

Controlling phosphorus loadings from wastewater treatment facilities has improved water quality. In the case of Lake Washington, diversion of sewage effluent decreased summer chlorophyll-a concentrations by 28% (Edmonson, 1972). Lake Erie, was once considered all but lost, but efforts to control phosphorus loading have brought the lake back. In the early 1970s, it was not unusual to find mounds of algae washed up on the beaches of Lake Ontario, in Rochester, New York. Efforts to control eutrophication in the Great Lakes have also brought Lake Ontario back to health, and residents are determined to keep it that way. Generally where lakes have not responded to nutrient load reduction, lakes are shallow and significant recycling from phosphorus-rich sediments has hampered recovery.
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Fork River Basin Project, Office of Governor, Helena, Montana.


Nutrient Considerations

The Missoula Wastewater Treatment Plant (MWTP) adds a significant amount of phosphorus to the Clark Fork River. Thirty-four percent of the downstream total phosphorus load in the Clark Fork River is believed to come from the MWTP (MDHES, 1985). The MWTP may also supply 6% of Lake Pend Oreille's total phosphorus load (MDHES, 1986).

Phosphorus data on the MWTP effluent and ambient river concentrations above and below the plant are presented in Table 1. Water Quality Bureau monitoring of the plant and river showed that, from 1985 to 1987:

--- the MWTP had an annual average total phosphorus concentration of 5.5 mg/l and emptied 50 tons/year total phosphorus into the Clark Fork River.

--- 41 tons/year (82%) of the total phosphorus load from the plant was orthophosphorus.

--- Ambient total phosphorus concentrations in the river increased by 58% as a result of phosphorus loading from the plant.

--- Ambient orthophosphorus concentration in the river nearly doubled as a result of phosphorus loading from the plant.

--- Ongoing studies suggest MWTP's effect on
river levels of soluble reactive phosphorus (most bioavailable form) is even greater (V. Watson, personal communication).

In addition, a Preliminary Environmental Review prepared to assess the plant's discharge permit pointed out that concentrations of total phosphorus in the river exceeded the 0.05 mg/l P nuisance algal growth criteria, 14 out of the 34 months sampled.

**TABLE 1.**

ANNUAL AVERAGE PHOSPHORUS LOADS AND CONCENTRATIONS
(CLARK FORK RIVER AND MWTP)
1985 TO 1987
Source: MDHES, 1988

<table>
<thead>
<tr>
<th>Source</th>
<th>Tons/Yr</th>
<th>mg/l</th>
<th>Tons/Yr</th>
<th>mg/l</th>
<th>Ortho-P% of load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above MWTP</td>
<td>79.7</td>
<td>0.03</td>
<td>45.5</td>
<td>0.017</td>
<td>57%</td>
</tr>
<tr>
<td>MWTP Discharge</td>
<td>49.7</td>
<td>5.47</td>
<td>41</td>
<td>4.55</td>
<td>82%</td>
</tr>
<tr>
<td>Below MWTP</td>
<td>125.9</td>
<td>0.055</td>
<td>89</td>
<td>0.04</td>
<td>71%</td>
</tr>
<tr>
<td>(Schuffield's)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TP - total phosphorus
OP - orthophosphorus

In the Draft EIS on the Frenchtown pulp mill (MDHES, 1985), effluent phosphorus from the MWTP was also cited as a possible cause of increased total phosphorus concentrations in the river below the plant. The report noted that phosphorus concentrations in the river exceeded the nuisance algal growth threshold 9 out of 25 times
sampled in 1982 above the Thompson Falls reservoir. In addition, the MWTP increased the Clark Fork River total phosphorus concentration by 34%.

To make matters worse, phosphorus load from the MWTP is projected to increase (Table 2). The City of Missoula plans to add many more hundred homes to the current sewer system in the near future (Joe Aldegarie, personal communication). An area along Reserve Street, a portion of the Rattlesnake, and the Wapikiya-Belvue area are slated for immediate annexation as funds become available. This will increase flow and effluent phosphorus loading from the MWTP to the Clark Fork River.

**TABLE 2**

**SUMMARY OF FLOWS AND LOADINGS**
**MISSOULA WASTEWATER TREATMENT EFFLUENT**
Source: MDHES, 1988

<table>
<thead>
<tr>
<th>Year</th>
<th>Annexed Avg. Population</th>
<th>MGD</th>
<th>Avg. Month</th>
<th>-------- lb/day</th>
<th>Loadings--------</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BOD</td>
<td>TSS</td>
</tr>
<tr>
<td>1980</td>
<td>26,600</td>
<td>6.43</td>
<td>1,340</td>
<td>804</td>
<td>182</td>
</tr>
<tr>
<td>1982</td>
<td>27,976</td>
<td>5.78</td>
<td>1,127</td>
<td>544</td>
<td>638</td>
</tr>
<tr>
<td>*1985</td>
<td>29,890</td>
<td>6.10</td>
<td>1,271</td>
<td>1,017</td>
<td>996</td>
</tr>
<tr>
<td>1990</td>
<td>33,080</td>
<td>7.71</td>
<td>1,606</td>
<td>1,286</td>
<td>1,025</td>
</tr>
<tr>
<td>1995</td>
<td>36,280</td>
<td>8.35</td>
<td>1,740</td>
<td>1,393</td>
<td>1,110</td>
</tr>
<tr>
<td>2000</td>
<td>39,500</td>
<td>8.99</td>
<td>1,873</td>
<td>1,500</td>
<td>1,195</td>
</tr>
</tbody>
</table>

* based on 1984-1986 averages.
City officials believe phosphorus loading from the MWTP will increase, but they argue that loading to the river overall may not. They claim by annexing homes in Missoula, phosphorus loading from septic system drainfields will be reduced, and therefore loading to the river may actually decrease.

They have a point. Soils in and around Missoula are known to have poor phosphorus filtering capacities, and phosphorus may be reaching the Clark Fork from septic drainfields (Verhay, 1987). In addition, conventional activated sludge facilities remove between 20-40% of the total phosphorus from raw wastewater (Black, 1984). A portion of the phosphorus from annexed homes will be removed during treatment at the plant. The question is, does the soil provide equal or better phosphorus removal than the MWTP? Without in-depth studies on phosphorus mobility in Missoula septic drainfields and an analysis of current phosphorus removal efficiency at the plant, this question can not be answered. The plant's phosphorus removal efficiency can be determined by monitoring the influent total phosphorus.

It appears a more restrictive limit on total phosphorus loading from the MWTP may be instituted. The City of Missoula has favorably endorsed the adoption of a discharge permit primarily based on the plant's 1982 total phosphorus load. The Frenchtown pulp mill was the first point source
along the Clark Fork to accept a permit limiting its phosphorus discharge to the level existing in 1982. To reach this goal, the City may adopt a phosphate detergent ban. The City also plans to study the feasibility of a land application system for treatment of the plant's effluent during the warm weather months. Both a phosphate detergent ban and land application of the plant's effluent will reduce the phosphorus load to the Clark Fork River.

Periphyton Productivity Above And Below The MWTP

Periphyton accumulation on artificial substrates

In July and August 1984, the Water Quality Bureau investigated the growth rate of attached algae on artificial substrates as a measure of stream productivity. At a site above the MWTP and at two sites below -- the Schuffield site (two miles below) and Harpers Bridge (below the confluence of the Bitterroot River) -- mean values for chlorophyll-a and biomass production were determined (Table 3). The Water Quality Bureau drew the following conclusions from the study:

End of MWTP's Mixing Zone (Two Miles Below MWTP)

--- chlorophyll-a accrued at over four times the rate compared to the site above the MWTP.
--- biomass accrued at nearly twice the rate compared to the site above the MWTP.
--- nutrient contributions from the MWTP were
directly responsible for increased algal productivity.

Below The Bitterroot River (Harpers Bridge site)

--- chlorophyll-a accrued at a rate 25% greater than the site two miles below the MWTP.

--- biomass production accrual was 5% greater than the site two miles below the MWTP.

--- nutrient contributions from the MWTP and the Bitterroot River were responsible for increased algal productivity.

**TABLE 3.**
**PERIPHYSIS PRODUCTION ON ARTIFICIAL SUBSTRATES**
**CLARK FORK RIVER**
**Source: MDHES, 1988.**

<table>
<thead>
<tr>
<th>Source</th>
<th>Chlorophyll-a Accrual</th>
<th>Biomass (AFDW)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mg/m2/day</td>
<td>mg/m2/day</td>
</tr>
<tr>
<td>Above MWTP 7/26-8/9/84 (14.2 days)</td>
<td>0.155</td>
<td>61.5</td>
</tr>
<tr>
<td>End of Mixing Zone 7/25-8/9/84 (14.8 days)</td>
<td>0.673</td>
<td>123.8</td>
</tr>
<tr>
<td>Below the Bitterroot 7/25-8/10/84 (14.2 days)</td>
<td>0.878</td>
<td>130.2</td>
</tr>
</tbody>
</table>

**Periphyton standing crop on natural substrates**

The point at which algal standing crops no longer protect aesthetic values and aquatic life in the Clark Fork
River has not been established, but such criteria have been established by British Columbia. The Canadian algal standing crop criteria for the protection of aesthetic values is 50 mg/m². The criteria for protecting aquatic life is 100 mg/m² (MDHES, 1988). Comparing algal standing crop in the Clark Fork River (Table 4) against the Canadian criteria, the following observations can be made:

--- Algal standing crop in the Clark Fork River exceeds Canadian criteria for both the protection of aesthetic values and aquatic life.

--- Algal standing crop productivity is greater below the MWTP compared to above, with the site two miles below 1.5 times greater and the Harpers Bridge site (below the confluence of the Bitterroot River) nearly two times greater.

--- Increased algal standing crop productivity at the site two miles below the MWTP is likely due to nutrient loading from the MWTP, and increased algal standing crop productivity at the Harpers Bridge site is likely due to nutrient loading from the MWTP and the Bitterroot River.

Caution should be used in drawing conclusions from the British Columbia algal standing crop criteria. The
criteria set in British Columbia may not be applicable to the Clark Fork River Basin.

TABLE 4.
PERIPHYTON STANDING CROP PRODUCTIVITY
CLARK FORK RIVER

<table>
<thead>
<tr>
<th>Source</th>
<th>Chlorophyll-a mg/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above MWTP 9/10/86</td>
<td>157.9</td>
</tr>
<tr>
<td>Two Miles Below MWTP 9/10/86</td>
<td>225.4</td>
</tr>
<tr>
<td>Harper Bridge 9/10/86</td>
<td>352.2</td>
</tr>
</tbody>
</table>

Algal assays

Algal growth potential in the waters of the lower Clark Fork indicate the MWTP is a major source of growth stimulating nutrients on the river (Greene, et. al., 1984, 1985, 1986). Algal assays performed in August of 1985 (Greene, et. al., 1986), when the river is most susceptible to the effects of high algal productivity because of low flow and high temperatures, suggests algal growth potential increased from below the Milltown Dam to a site above the Frenchtown Pulp Mill (Figure 2). Algal growth potential increased from Superior to the Thompson Falls reservoir as well. This indicates two continuing sources of phosphorus, one possibly being the MWTP, and another unknown source below Superior.
FIGURE 2
PRODUCTIVITY CLASSIFICATION OF LOWER CLARK FORK RIVER
Source: Greene, et. al., 1986.

Site Identification
10 Below Milltown Dam
11 Above MWTP
12 Harper Bridge (above Champion)
13 Huson (below Champion)
14 Superior
15 Above Flathead River Confluence
16 Above Thompson Falls Reservoir
17 Below Thompson Falls Reservoir
18 Below Noxon Dam
Algal productivity yields were termed moderate by the EPA for most of the lower Clark Fork, and were moderately high at only three locations on the river: above the Thompson Falls reservoir, and directly above and below the MWTP. Although algal yields increased below the MWTP, algal yields above the plant were already termed moderately high, and loading from the plant did not stimulate algal growth to a level considered high by the EPA (Greene, et. al., 1986).

However, algal productivity from above to below the MWTP increased three fold. Between Superior and the Flathead River confluence, algal yield increased about five fold, but the magnitude of this increase is less than that which occurs from above to below the sewage plant. Algal yield increased by about 20 mg/l from above to below the sewage plant, while between Superior and the Flathead River confluence algal yield increased by a factor of less than one mg/l (Figure 2). Moreover, the jump between Superior and the Flathead River confluence may be exaggerated. Algal growth potential at Superior may have been retarded by toxic concentrations of zinc identified at the site upstream. It is hard to understand the complex biological interactions occurring in rivers; however, effluent from the MWTP substantially stimulates algal growth in the Clark Fork River.
References

Aldegarie, Joe,. personal communication.


Greene, et. al., 1986. Results of algal assays performed on the waters collected from the lower Clark Fork River at stations below Milltown Dam to below Noxon. Report No. 3, August 6-8, 1985 sampling. Northrop Services Inc., Hazardous Waste and Water Branch, Corvallis, OR.


A Historical Perspective

In 1963, the City of Missoula constructed a primary treatment facility capable of handling 5 million gallons/day (MGD). Concerned about the quality of the effluent, in 1976 the City upgraded the plant to secondary treatment. Since 1976, the City has periodically improved the plant's effectiveness and capacity. Plant modifications were made in 1982, 1985, and 1986. The latest improvements included a new headworks structure, anaerobic digester, secondary clarifier, and diffuse aeration system. The plant currently has the capacity to treat 8.5 to 9.0 MGD. Since 1976, nearly 7 1/2 million dollars have been spent to improve the plant (Process Applications Inc, 1988).

The facility has no nutrient removal capacity except that normally found in conventional activated sludge secondary treatment. Years ago, surface water eutrophication was an intangible, confusing process just beginning to gain public recognition. Some municipalities designed or modified facilities in the 1960s for nutrient removal, but for most simply having a sewage treatment plant was a step forward. Like many city governments, the City of Missoula never dreamed of a time when nutrient removal would become necessary.

Having spent time and resources on improvements at the MWTP, City officials are reluctant to ask residents to foot
the bill for more improvements. Today Missoula is considered by many to be in a state of economic depression, and citizens are conscious of their pocket books. Increased sewer fees are not a popular subject.

Still many citizens consider the Clark Fork River Lake Pend Oreille ecosystem to be in trouble. Economic troubles and short sighted planning have made the Clark Fork River Basin susceptible to water quality degradation. Industry, municipalities, loggers, farmers and others must work together if this invaluable resource is to be saved from further degradation.

The City of Missoula can get financial assistance from the federal government if they choose to remove phosphorus at the MWTP. In 1954 the federal government, concerned about the nation's surface waters, began subsidizing sewage treatment projects. Between 1956 and 1972, under PL 84-660, 13,764 projects were assisted for a total of $5.2 billion in grants (Feliciano, 1982). In 1972, the Congress passed the Federal Water Pollution Control Act, and along with it PL-92-500, in which municipalities could obtain funds for sewage treatment plant construction and modification. The construction of the Missoula Plant and its modifications were made possible by funds provided under this legislation. The EPA construction grant program still exists today.
Process Flow Description

The general flow diagram of the MWTP is shown in Figure 3 and described below.

Raw wastewater enters the plant and is lifted with the plant return flows to the headworks. In the headworks, the wastewater flows through a mechanical bar screen and into the aerated grit basins which remove large debris from the raw wastewater. The water stream is then divided by a splitting structure into three primary clarifiers. In the clarifiers more solids are settled out. The primary clarifier effluent is recombined and pumped to four aeration basins where microorganisms facilitate further solid and BOD reduction. The effluent from the aeration basins is split between three final clarifiers. The water is chlorinated (June-September) and discharged into the Clark Fork River (Montgomery, 1986).

At timed intervals, sludge from the primary clarifiers is pumped to the primary digesters. Some of the waste-activated sludge from the secondary clarifiers is returned to the aeration basins to maintain an adequate microorganism population. Another portion is thickened by dissolved air flotation, and then pumped to the anaerobic digesters. Digested sludge is dewatered, and trucked to either a landfill or agriculture site.
FIGURE 3
PROCESS FLOW DIAGRAM
MISSOULA WASTEWATER TREATMENT PLANT
Wastewater Characteristics

Some of the MWTP's wastewater characteristics are shown in Table 5. In general, the plant removes BOD and TSS effectively, with removal of 90 and 94%, respectively. In 1987, the monthly average concentrations for BOD and TSS were 24 mg/l and 16 mg/l respectively. However, the MWTP has had difficulty maintaining effective BOD and TSS removal on a daily basis. In 1987, the City of Missoula was fined for exceeding effluent limitations of BOD (MDHES, 1988). In fact, effluent BOD limitations have been exceeded each year since 1980.

| TABLE 5 |
| WASTEWATER CHARACTERISTICS AT THE MISSOULA WASTEWATER TREATMENT PLANT |

<table>
<thead>
<tr>
<th></th>
<th>Influent mg/l</th>
<th>Effluent mg/l</th>
<th>% Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD</td>
<td>231</td>
<td>24</td>
<td>90</td>
</tr>
<tr>
<td>TSS</td>
<td>256</td>
<td>16</td>
<td>94</td>
</tr>
<tr>
<td>TP</td>
<td>---</td>
<td>6.23* (5.47)</td>
<td>---</td>
</tr>
<tr>
<td>TN</td>
<td>---</td>
<td>18</td>
<td>---</td>
</tr>
<tr>
<td>Temperature</td>
<td>10-18 C</td>
<td>10-18 C</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>6.8-7.2</td>
<td>6.95-7.3</td>
<td></td>
</tr>
</tbody>
</table>


Removal efficiency of nitrogen and phosphorus is unknown since influent concentrations are not measured.
Average monthly effluent concentration for total nitrogen was 18 mg/l in 1987, and is nearly three times the total phosphorus effluent concentration. Temperature and pH remain fairly constant throughout treatment. Wastewater temperature varies with seasons.

The monthly average effluent total phosphorus concentration of 6.23 mg/l calculated using the MWTP self monitoring data is significantly higher than the Water Quality Bureau's estimate of 5.47 mg/l. This is a function of sample replication and timing. The MWTP staff samples for phosphorus more frequently, and probably has a better estimate of the effluent phosphorus concentration.

Sources And Forms Of Phosphorus In Sewage

It is important to understand where wastewater phosphorus originates and how it is altered during treatment. Wastewater phosphorus comes from human excrement and cleaning supplies. The latter includes such cleaning agents as tub and tile cleaner, cleansers, chemical water conditioners, and laundry products. Laundry detergent phosphorus accounts for a significant amount of wastewater phosphorus. The amount varies from one municipality to the next, but it is generally in the range of 25 to 50% (Wallgren, 1977).

There are three forms of phosphorus in raw sewage: organic phosphorus found in organic matter and cell protoplasm, complex inorganic phosphates (polyphosphates)
found in detergents, and soluble inorganic orthophosphate. In a continuous cycle, polyphosphate and organic phosphorus are converted to soluble orthophosphate during wastewater treatment. Some organic phosphorus compounds resist conversion and become incorporated in the sludge. A portion of the soluble orthophosphate is utilized by microorganisms, the rest eventually leaves the plant. It is important to consider phosphorus conversion during sewage treatment when selecting phosphorus removal processes. To be effective a phosphorus removal process should remove soluble orthophosphate as well as total phosphorus.
References


PHOSPHORUS REMOVAL PROCESSES

A phosphorus removal process must not upset current treatment efficiency at the plant. The activated sludge plant in Missoula is a living system, where wastewater is detoxified by microorganisms requiring a carefully controlled environment. The plant's ability to treat waste is dependent on maintaining a healthy, vigorous microbial population. Costs to the environment and citizens of Missoula must also be minimized when phosphorus reduction is attempted in Missoula. For these reasons, the following alternatives for removing or reducing phosphorus load from the MWTP will be discussed:

--- Modifying Activated Sludge Operations
--- A Phosphate Detergent Ban in Missoula County
--- Chemical Precipitation
--- Biochemical - PhoStrip
--- Land Application

MODIFYING TREATMENT OPERATIONS AT THE MWTP

Phosphorus removal in the activated sludge system is limited by the nutritional requirements of the activated sludge microorganisms, organic matter resistance to phosphorus solubilization, and clarifier performance. Phosphorus removal in activated sludge systems can be enhanced by increasing clarifier performance, increasing
phosphorus uptake by microorganisms, or by preventing the recycling of phosphorus during sludge handling operations (Milbury, McCauley, and Hawthorne, 1971; Garber, 1972; Barnard 1976; Tetrault, et. al., 1986).

Garber (1972) noted phosphate removal efficiency was limited by the influent carbon-to-phosphorus ratio. By adding glucose to the influent, phosphorus removal efficiency could be enhanced. Tetrault, et. al., (1986) supported this idea, suggesting that an influent BOD to total phosphorus ratio greater than 20 was necessary for favorable clarifier performance and effective phosphorus removal.

An influent carbon-to-phosphorus ratio at the MWTP can not be determined because influent phosphorus is not monitored. However, the MWTP's influent carbon-to-phosphorus ratio is probably above twenty. The influent BOD is 231 mg/l (Table 5), requiring a total phosphorus concentration above 11.0 mg/l before the carbon-to-phosphorus ratio would dip below twenty. The 1987 total phosphorus concentration after primary treatment was 6.9 mg/l (MWTP, self monitoring data), suggesting the influent total phosphorus concentration is below 11.0 mg/l.

Heim (1980) and Barnard (1976) indicated phosphorus removal could be improved by creating an anaerobic stage prior to aeration during treatment. Creating an anaerobic stage prior to aeration at MWTP, may enhance phosphorus
removal. This method involves forcing microorganisms through an anaerobic-aerobic staging process which enhances the phosphorus absorptive ability of the microbial population (Heim, 1980). Significant phosphorus removal, however, can only be maintained if microorganisms do not later encounter another anaerobic environment. A second anaerobic environment releases the phosphorus within cells of the microorganisms. At MWTP, the anaerobic digesters function as a second anaerobic environment, but if this process can remove any additional phosphorus it should not be overlooked.

Milbury, McCauley, and Hawthorne, (1971) suggested removal effectiveness could be augmented by preventing phosphorus recycling during sludge handling operations. At the Missoula plant, phosphorus recycling during sludge handling operations may be controlled by: (1) Removing solids rapidly from the secondary clarifiers to prevent anaerobic conditions which resolubilize phosphate. This generally means maintaining a sludge blanket between 1 to 2 feet. (2) Wasting excess sludge on a continuous basis, thus avoiding abrupt wasting of significant amounts of sludge. (3) Operating the activated sludge system at aeration suspended solids levels equal to or greater than 1200 to 1300 mg/l. (4) Maintaining dissolved oxygen levels in wastewater sent to the secondary clarifiers between 3 and 4 mg/l (Milbury, McCauley, and Hawthorne, 1971).
As long as effective solid-liquid separation takes place and development of anaerobic conditions in the sludge is minimized to prevent phosphorus resolubilization, maximum phosphorus removal at the current Missoula plant can be achieved. Milbury and associates noted varying clarifier detention times from 1.5 to 6 hours did not affect phosphorus removal efficiency, nor did parameters such as nitrification, hydraulic loading, temperature, primary effluent suspended solids, and pH. Plant operators in Missoula may want to experiment with the ideas presented.
References


PHOSPHATE DETERGENT BAN IN MISSOULA COUNTY

Using a phosphate detergent ban to control eutrophication is not a new concept. Indiana, Michigan, Minnesota, New York, Wisconsin, and even the city of Chicago, all have phosphate detergent bans. Limiting phosphorus content in laundry detergents, in conjunction with sewage treatment phosphorus removal, has resulted in dramatic reductions in phosphorus loadings to the Great Lakes. Flathead and Lake counties in Montana adopted a phosphate detergent ban to control eutrophication in Flathead Lake.

The Ban And Eutrophication In The Clark Fork Basin

MWTP effluent total phosphorus concentration might be reduced by approximately 25% if a phosphate detergent ban was implemented countywide. This is a conservative estimate. Brooks and Doemel (1975) attributed a 57% reduction in effluent total phosphorus to a ban. Likewise, Maki, et. al., (1984) suggested that effluent total phosphorus may be reduced by 50% when a ban is instituted. Four wastewater treatment facilities in Flathead and Lake counties showed similar results after a ban was adopted (Figure 4). At the Big Fork plant, preliminary results show that effluent total phosphorus concentrations decreased by approximately 62%. A 36% average reduction was achieved comparing pre and post ban periods for all four plants.
Missoula County may have a comparable reduction if a ban is enacted; however, a 25% reduction is a good conservative estimate. Reduction data in the 1970s is likely an overestimate of what would occur if a ban was implemented today, as phosphorus content in detergents has steadily come down over the past 10 to 15 years (Jones and Lee, 1986). States with long-standing bans estimate a 20-25% reduction. In two cases where a ban has been initiated since 1972, the reduction has been in the area of 25%. In Michigan, the reduction in effluent total phosphorus was 24%, while in Madison, Wisconsin it was 22% (Hartig and

A phosphate detergent ban removes the form of phosphorus that is most available to algae and plants. Recall that during wastewater treatment, polyphosphates found in detergents are converted to bioavailable soluble orthophosphate. In controlling the phosphorus content in laundry detergents, algal growth is directly reduced.

A phosphate detergent ban in Missoula County may not change the trophic status of Lake Pend Oreille. In general, a 20% reduction in total phosphorus loading is needed to change the trophic status of a water body (Jones, Rast and Lee, 1978). At this time, it is unknown how much phosphorus would be diverted from Lake Pend Oreille if a ban in Missoula County is adopted but a 20% is unlikely.

Still water quality in the basin may improve. Lake chlorophyll-a concentrations are directly related to levels of phosphorus loading (Smith and Shapiro, 1981), and a smaller percent reduction in bioavailable phosphorus may have a measurable effect. As for the river below the MWTP, bioavailable phosphorus levels should drop dramatically with a phosphate detergent ban.

In addition to controlling phosphorus loading from the MWTP, a phosphate detergent ban would reduce loading from septic tanks and sewer overflows. In Michigan, it was estimated that a phosphate detergent ban resulted in a 33%
reduction in the amount of phosphorus entering Michigan's lakes from septic system drainfields (Heidtke, Scheflow, and Sonzogni, 1980). There are many people in Missoula county using septic systems. In many places, the water table is also above the sewer main throughout much of the year. According to the City of Missoula Public Works Director, as much as 40% of the flow to the MWTP comes from ground water leaks in the sewer line (Joe Aldegarie, personal communication).

Monetary Benefits Associated With A Phosphate Detergent Ban In Missoula County

If the City of Missoula implements a chemical phosphorus removal system, an accompanying phosphate detergent ban would result in lower operational costs (see next section). Because the amount of metal salt needed to remove phosphorus via chemical precipitation depends on the influent phosphorus concentration (EPA, 1976), a phosphate detergent ban that reduces influent phosphorus concentration would also reduce chemical dose requirements. Operational cost reductions could also be realized in sludge handling. The less chemical used, the less sludge produced.

Savings could be significant. By the year 1990, it is estimated that phosphate detergent bans will result in savings of $14 million/yr in chemical and sludge handling costs at U.S. municipal treatment plants (Heidtke,
Scheflow, and Sonzogni, 1980). In Minnesota, a 20-30% reduction in phosphorus removal costs were realized after a ban was implemented. In Canada, chemical phosphorus removal costs at wastewater treatment facilities in no-ban areas were 37% higher than those with a ban. If a ban is adopted in Missoula county to complement a phosphorus removal process using metal salts, savings are likely.

There may be other savings associated with a phosphate detergent ban that are not directly seen by the City of Missoula. The phosphorus in laundry detergents can be used for other purposes if a ban is adopted. This would reduce the demand for phosphorus in the market and reduce costs of phosphorus-based products, thus saving consumers money.

Environmental Benefits Associated With A Phosphate Detergent Ban In Missoula County

Besides controlling eutrophication, a phosphate detergent ban makes good sense for other environmental reasons. Among those, is the need to slow consumption of phosphorus supplies nationwide. Phosphate rock supplies mined for use in fertilizers, laundry detergents, and many other products are dwindling in the United States. Given a 1968 production of 11.3 million tons of phosphorus per year and a world population of 3.6 billion growing at a rate of 1.9% per year, it has been estimated that the economic reserve of phosphate rock will be exhausted in about 90 years (Wells, 1975). Donald Emigh, the director of mining
for Monsanto Industrial Chemicals Company, predicted economic supplies at 1968 social consumption would last for 226 years (Wells, 1975). Given that Emigh has a vested interest in maintaining high phosphorus consumption, his estimate may be questioned. Nonetheless, it appears that economic supplies of phosphate rock are limited.

More low grade phosphate rock exists worldwide, but more intensive mining would be needed to extract the ore at heavy costs to consumers and the environment. It would seem conservation on any level would alleviate some of the problem.

If a phosphate detergent ban is instituted in conjunction with chemical phosphorus removal, soils and ground water supplies in Missoula County may benefit. Liquid sewage sludge from the MWTP is spread on agricultural land from approximately April to October (MWTP self monitoring data). During the winter months, liquid sludge is hauled to a private composting operation. While land spreading of sewage sludge may pose no immediate threat to soils and ground water supplies in the valley, the assimilation capacity of valley soils may be exhausted in the long term. Slowly land and ground water supplies around Missoula may become degraded by sludge application. Reducing sludge application would seem advantageous.

Generating less sludge also reduces energy consumption. Fewer trucks would be required to transport the sludge to
agricultural sites and private compost. In addition, less energy would be needed for sludge digestion.

Nonphosphate Detergents And Wastewater Treatment

Nonphosphate detergents do not adversely affect wastewater treatment. The presence of Nitriloacetate (NTA) or citrate at levels up to 15 mg/l did not interfere with phosphorus removal by chemical precipitation (Shannon, 1980). E.E. Shannon suggested 92% of citrate degraded in secondary treatment plants, and 80-90% of zeolites were removed if only this type of detergent is used. Moreover, nonphosphate detergents had no effect on biological oxygen demand and suspended solids removal.

While NTA has no deleterious effect on wastewater treatment, it may adversely affect surface waters. NTA degrades during wastewater treatment and is released as inorganic nitrogen to the environment (Hamilton, 1972). This may increase algal productivity in nitrogen limited waters. Suprisingly, Scott Anderson at the Water Quality Bureau was aware of no deleterious impacts of nonphosphate detergents on the environment (Scott Anderson, personal communication). The United States government waited until 1981 to allow the use of NTA-based detergents because of the potential environmental problems with NTA. Because of pressure from the detergent industry and the fact that the Canadian government has endorsed the use of NTA for several years, the U.S. allowed consumers to buy NTA-based
detergents.

Acceptance Of A Phosphate Ban

Ultimately, the success of a phosphate detergent ban rests on the willingness of Missoula County citizens to accept the ban. In Indiana, of 231 persons interviewed, 70% were satisfied with their substitute detergents, and of the remainder, 40% still supported the ban (Wallgren, 1977). In Flathead and Lake Counties, the only complaint the Flathead Basin Commission has received is that the ban does not include other cleaning products besides laundry detergents (C. Hess, personal communication).

The most promising example of the widespread acceptance of bans, is the number of states and municipalities who have remained committed despite detergent industry opposition. In July 1976, over 47 million Americans lived in areas with bans (Glassman and Oliver, 1980). Since then, the number has risen. No registered complaints have been filed in Eric City, New York, Dade City, Florida, or Chicago, Illinois (Wallgren, 1977).

But there was a time when complaints were made about nonphosphate detergents. In the 1970s, consumers in every Great Lake state complained about the laundering performance of nonphosphate detergents (Glassman and Oliver, 1980). Apparently, nonphosphate detergents available at the time did not clean clothes as effectively as phosphate types. Sodium carbonate detergents
supposedly increased carbonate deposition causing premature fabric wearout and washing machine breakdown. The EPA voiced concern about using nonphosphate detergents claiming that nonphosphate detergents had comparable performance to phosphate detergents in waters of low hardness, but did not perform quite as well in moderately hard water, and in extremely hard waters, both types performed poorly (Wallgren, 1977). The hardness of the water in Missoula is approximately 170 mg/l CaCO3 (Mr. Lucasic, personal communication). Major problems associated with laundering performance of nonphosphate detergents should not arise.

The detergent industry opposed the use of nonphosphate detergents as well. Homemaker Testing Corporation (HTC) and Proctor and Gamble (P&G) suggested that nonphosphate detergents cleaned poorly, and that consumer cost in banned areas would increase because more detergents, hotter water, and more energy would be needed to clean clothing effectively (Glassman and Oliver, 1980; Wallgren, 1977). Homemaker Testing Corporation estimated an annual increase in expenditures of $23.27 per family per household, Proctor and Gamble estimated $5.17, and in a similar study Glassman and Oliver, $11.10 (Wallgren, 1977; Glassman and Oliver, 1980).

But according to the EPA, both the HTC and P&G studies were misleading because they made invalid comparisons by
selecting ban areas with poorer water quality than the no-ban areas (Wallgren, 1977). Water hardness, known to affect the degree of carbonate deposition, was substantially higher in the no-ban area, resulting in poorer laundering performance and higher penalties. In addition, results in the Glassman-Oliver report may have been misleading because laundering performance was evaluated using 100% cotton with a detergent containing 70% sodium carbonate. No detergents today contain sodium carbonate levels that high.

In fact, nonphosphate detergents have been improved greatly. Nonphosphate detergents differ from conventional brands in that each has a different builder, a nonprecipitating inorganic compound which assists cleaning by softening the washwater and keeping dirt in suspension. In phosphate brands, the builder is sodium tripolyphosphate, or STP. Nonphosphate substitutes can contain a variety of builders including sodium nitriloacetate (NTA), sodium carbonate, citrates, and zeolite (Flynn, 1984; Saadia, 1982).

Today a variety of nonphosphate detergents exist, each able to clean clothing as well as phosphate types. There is still concern over using sodium carbonate types in extremely hard water (Saadia, 1982); however, enough high quality substitutes of different composition exist that consumers have a choice on what nonphosphate detergent they
use. In 1981, the U.S. government passed legislation allowing the use of NTA in nonphosphate detergents (Craig Hess, personal communication), and, with it, nonphosphate detergents became an instant success. Proctor and Gamble have test marketed substitute detergents and found NTA to be the most effective builder (Flynn, 1984).

In addition, nonphosphate brands have become increasingly popular. It is likely some residents of Missoula County use nonphosphate detergents without even knowing it. In 1975, 19.3% of the liquid laundry detergent market in no-ban areas contained no phosphorus (Wallgren, 1977). Today, every manufacturer prepares a phosphate and a nonphosphate type. Detergents such as ERA Plus, Tide, Purex, All, and Arm and Hammer contain no phosphorus (Appendix A). Nonphosphate detergents are even manufactured in Helena, Montana (Appendix A). Product distribution and consumer acceptance should not be a major problem.

Enforcement Of A Phosphate Ban

The passing of House Bill 711 banning phosphate detergents in Flathead and Lake counties has opened the door for the City of Missoula to follow suit. House Bill 711 was a model rule that allows counties to adopt an ordinance to prohibit the sale of laundry detergents containing phosphorus. Any county can now pass an ordinance to implement a ban, but under HB 711, the county
adopting an ordinance must have a natural lake. In addition, other efforts besides a ban must be undertaken to reduce the amount of phosphorus entering surface waters. At this time, the City of Missoula may pass an ordinance to ban phosphate detergents under its home rule powers, but if Missoula County wants to initiate a ban, under HB 711, the state must first certify that a natural lake in the county is experiencing cultural eutrophication, and other steps such as phosphorus removal must also be planned.

Fortunately, if the City of Missoula adopted a ban, in all likelihood the County would be adopting a ban. Many supermarkets in rural towns of the County receive laundry detergents directly from Missoula merchants. If not directly, rural shipments probably arrive on the same manufacturer shipments. A phosphate detergent ban in Missoula County might be accomplished without passing an ordinance at the state level.

Guidance from the Water Quality Bureau and the Flathead Basin Commission is advised to make the transition smoother. The County Health Department enforces the ban in Flathead County (C. Hess, personal communication). Likewise, the Health Department in Missoula County could do the same. To ensure that supermarkets are following the ordinance, Health Department officials could inspect store shelves as part of the State routine inspection of grocery stores requiring minimal staff time for enforcement. A
phosphate detergent ban in Missoula County can become a reality with little planning.

City officials should control the amount of NTA-based detergents stocked throughout supermarkets in the county. The Clark Fork River is known to be nitrogen limited at times (Greene, et. al., 1986), and inorganic nitrogen loading from the MWTP should be minimized.
References

Anderson, S., personal communication.


Lucasic, M., Mountain Water Company, personal communication.


Missoula Wastewater Treatment Plant, Self Monitoring Data.


Watson, V., Modeling In-Lake Total Phosphorus Concentration in Lake Pend Oreille, Idaho, in review.


CHEMICAL PRECIPITATION OF PHOSPHORUS

Chemical precipitation of phosphorus is time proven. Since the 1960s, phosphorus has been effectively removed with chemicals (Barth and Ettinger, 1967). Under the Canada-Ontario Agreement, in which wastewater treatment plants around the Great Lakes were required to remove phosphorus, nearly 96% chose to do it chemically (Depinto, 1980). This removal process is also conceptually simple. Metallic ions such as aluminum, iron derivatives, or lime are added to wastewater to precipitate orthophosphate. During clarification the precipitants settle out and become incorporated into the sludge and are eventually wasted or recycled.

Iron derivatives and lime have been used to remove phosphorus (EPA, 1971), but only liquid alum will be analyzed as a phosphorus precipitate at the MWTP for the following reasons:

--- iron derivatives are highly acidic necessitating buffering with lime or sodium hydroxide, particularly in wastewaters of low alkalinity (EPA, 1976).

--- the use of iron derivatives has been shown to contaminate sludge with heavy metals (Black, 1984).

--- iron derivatives corrode metal pipes, increasing maintenance costs (EPA, 1976).
--- Lime as the sole precipitant is usually restricted to primary treatment because it raises the pH of wastewater and interferes with the biological process in aeration basins of secondary plants (EPA, 1976).

--- Lime contains high concentrations of inert materials which may wear out pumps (Black, 1984).

--- Liquid alum is manufactured in Missoula, Montana (Tom Lind, personal communication).

Process Description

While the removal process is conceptually simple, the chemistry of phosphorus removal with liquid alum is complex. Basically, orthophosphate in wastewater reacts with aluminum to produce aluminum phosphate (AlPO₄) (EPA, 1976). Some polyphosphates and organic phosphates are removed by the combination of more complex reactions and sorption on floe particles. Aluminum phosphate resists dissolution during sludge digestion and becomes a permanent constituent of the liquid or dewatered sludge.

Liquid alum has the approximate formula of Al₂(SO₄)₃•14 H₂O and a molecular weight of 594 (EPA, 1976). On the average, liquid alum contains about 4.37% aluminum. Alum will begin to crystalize around 30 degrees Fahrenheit, and becomes a solid at 18 F. Outdoor tanks should be heated to
keep alum temperature above 25 F to prevent crystallization.

No particular industrial hazards are encountered in handling alum. Liquid alum can be stored at the shipping concentration. Storage tanks may be open if indoors, and should be closed if outdoors. Tanks should be sized to handle approximately 1 1/2 times the normal shipment quantity. Usually, a ten day to two week supply should be kept on hand to avoid shipping problems.

Effectiveness

Influent total phosphorus can be reduced by 75% to 95% depending on the alum dosage. Liquid alum does not interfere with biological activities in the activated sludge system (Barth and Ettinger, 1967; EPA 1976). Processes such as biological nitrification and carbon and solids removal are in no way altered. In fact, the aluminum-rich sludge may have better settling characteristics (EPA, 1976). Alum adds a divalent ion (SO4) which has a proven coagulant benefit. In Ontario, where over 100 plants used alum to remove phosphorus, sludge was readily digestible in both existing aerobic and anaerobic digesters (Schmidtke, 1980).

The solubility of alum is pH dependent, and is lowest at a pH of approximately 5.5 to 6.5. This is the pH range for optimum phosphorus removal, although some removal occurs above pH 6.5. Alum reduces the pH of wastewater by
neutralizing the wastewater alkalinity and releasing carbon dioxide from carbonates during treatment. The higher the wastewater's alkalinity, the lower the pH reduction for a given alum dosage.

pH reduction realized with alum addition does not adversely affect wastewater treatment. Most wastewaters contain sufficient alkalinity, and rarely does the pH drop below the range of 6.0 to 6.5 (EPA, 1976). At normal hydraulic loading rates, alum dosages up to 125 mg/l should not adversely depress pH (Black, 1984).

Factors Controlling Phosphorus Removal Efficiency

Alum dosage

By controlling the alum dosage, phosphorus removal efficiency can be regulated. The alum dosage required is dependent on many factors, the most important of which is the wastewater phosphorus concentration. The higher the concentration, the greater the alum dosage required to remove a particular percentage of phosphorus. In Table 6, the alum-to-phosphorus weight ratio determines the percentage of phosphorus removed. For example, if the City of Missoula wishes to remove total phosphorus to a level of 1.0 mg/l in the effluent, approximately 85% of the wastewater phosphorus would need to be removed. In turn, a 16:1 alum to phosphorus ratio would be needed. The alum dosage would be determined by multiplying the phosphorus
concentration by 16 (EPA, 1976).

**TABLE 6**

PHOSPHORUS REMOVAL BY ALUM DOSAGE

<table>
<thead>
<tr>
<th>TP Reduction Required</th>
<th>Alum:P Weight Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>75%</td>
<td>13:1</td>
</tr>
<tr>
<td>85%</td>
<td>16:1</td>
</tr>
<tr>
<td>95%</td>
<td>22:1</td>
</tr>
</tbody>
</table>

(EPA, 1976)

**Point of Alum Addition**

Another parameter that affects phosphorus removal efficiency is the point in the treatment process where alum is added. As illustrated in Figure 5, there are six possible points of alum addition to the activated sludge system. Not all these points remove equal amounts of phosphorus at the same dosage level. Points 2, 3, and 4 require the least amounts of alum because the high surface area and sorptive properties of the floc reduce the chemical dosage needed. Greater dosages are required when introducing alum at point 5 because final effluent lacks high amounts of particulate matter. More alum would be needed at point 1 compared to 2, 3, or 4 because its total phosphorus concentration is usually higher, and organic phosphates and polyphosphates make up the bulk of the total phosphorus. Likewise, point 6 is not recommended for alum
addition because as much as 80% of the phosphorus precipitated may resolubilize during anaerobic digestion (Geinopolos and Vilen, 1971; Boyko and Rupke, 1976).

![Figure 5](image)

**FIGURE 5**
POSSIBLE ALUM ADDITION LOCATIONS - ACTIVATED SLUDGE PROCESS
Source: (Geinopolos and Vilen, 1971).

Alum addition at points 2, 3, or 4 makes sense operationally because it takes advantage of the activated sludge system. In order to remove phosphorus efficiently, flocculation of phosphorus-laden particulate matter should be promoted and the flocculated materials must be clarified (Geinopolos and Vilen, 1967). At points 1 or 5, virtually a whole new plant would need to be constructed to remove the phosphorus.
effectively.

Of points 2, 3, and 4, location 4 is the most advantageous (Black 1984). Comparing all the locations, 4 has the best mixing and flocculation potential. Location 4 also has the highest soluble orthophosphate concentration. Effective chemical phosphorus removal involves orthophosphate-alum precipitation, so alum should be added where orthophosphate concentrations are the highest.

To ensure the best location for phosphorus removal and dosages needed, jar tests are recommended prior to actual full-scale phosphorus removal (Boyko and Rupke, 1976; Black, 1984). A jar test is a simple procedure in which a sample of wastewater is taken at desired plant locations, and alum is added at various dosages to determine phosphorus removal efficiency. Usually a range of locations and dosages are tested. This should be done over an extended period of time, usually six weeks, in order to encounter a representative variety of sewage characteristics. It is also best to do the tests at various times of the day, or week (AWWA, 1964).

Clarifier performance

Phosphorus removal efficiency is closely related to solids removal efficiency. In fact, no matter how much alum is added, unless the effluent total suspended solids level can be reduced below 15 mg/l, it is impossible to achieve effluent total phosphorus less than 1.0 mg/l
(Black, 1984; Tetrault, et. al., 1986). While the MWTP's 1987 monthly average TSS concentration of 16 mg/l (Table 5) is close to the maximum acceptable TSS limit required for removal of total phosphorus to 1.0 mg/l, a few months had values as high as 30 mg/l (MWTP, self monitoring data). There appears to be no pattern to the higher TSS levels. This may jeopardize phosphorus control, especially during summer months when control is most crucial. According to the City's Public Works Director, the City plans to upgrade the secondary clarifier unit of the plant, which may make a 1.0 mg/l total phosphorus effluent attainable on a continuous basis using alum (Joe Aldegarie, personal communication).

Potential Problems Associated With Alum Addition

Alum addition will increase sludge volume. The question is -- how much? According to Boyko and Rupke (1976), liquid sludge volume may increase by 35%. They suggest that sludge solids will increase by 5-25%, and solids concentration of sludge will decrease, pushing the total volume to the aforementioned 35%.

Others have also reported an increase in sludge volume and decrease in solids concentration (Black, 1984; Schmidtke, 1980); however, they disagree with the magnitude of sludge increase reported in Boyko and Rupke (1976). Schmidtke (1980) suggests that sludge volume may increase by a maximum of 25%. He claims the sludge generated after
anaerobic digestion can be calculated using the equation:

$$0.0169 \times \left( \frac{\text{Sewered Population} \times 10^{-3}}{} \right) \times 10^6 \text{ gallons/yr}$$

With a Missoula sewered population of 33,400, this would produce an additional 893,810 gallons of sludge per year, an 5% increase in current sludge volume of 16,969,215 gallons per year (MWTP self monitoring data).

Black (1984) claims there are too many parameters which influence sludge quantity, and a generalization is the best that can be made until full-scale operation is adopted. He suggests the total sludge volume including phosphorus removal will approach 0.5% of the influent hydraulic load to the plant. Based on this estimate, a conventional activated sludge plant can chemically reduce the effluent's total phosphorus concentration to 1.0 mg/l without major expansion of sludge hauling facilities. At Missoula, assuming a 6.1 MGD influent hydraulic load, total sludge volume should be in the range of 30,000. At 9 MGD, approximately 45,000 gallons per day.

The anaerobic digesters at the MWTP may not be able to assimilate the 35% increase in sludge volume estimate by Boyko and Rupke (1976), or for that matter the 25% increase estimated by Schmidtke (1980). The anaerobic digesters at the plant are designed to provide a total detention time of 20 days at an average daily sludge volume of 55,000 gallons per day (Montgomery, 1986). The monthly average sludge loading to the plant digesters in 1987 was
46,491 gallons per day. Operationally, the digesters may be able to assimilate only a 16% increase in sludge volume.

Whether the digesters need to be run at or below design capacity for effective digestion was not known to plant operators that I questioned. However, the rest of the plant (exclusive of anaerobic digestion) is currently said to be operating at two thirds design capacity (6.1 MGD out of 9 MGD). Apparently, this assessment of design capacity does not include an assessment of sludge digestion, because based on the capacity of 9.0 MGD, the digesters should be able to withstand a 33% increase in sludge production.

Furthermore, a recent performance evaluation of the plant alluded to the limitations of the digesters but stated the performance potential may be improved by pumping a thicker sludge to the digesters (Process Applications Inc., 1988). It is clear that alum addition will not increase sludge thickness; in fact, it will decrease it. Whether alum addition will cause anaerobic digestion problems is unknown at this time.

Adding alum to the wastewater would also increase the concentration of aluminum and other heavy metals in the sludge. Metals are removed from wastewater by a series of complex chemical reactions. The following is a simplistic explanation of what occurs. Chemical phosphorus removal with alum removes some phosphorus in particulate form. Metals have a tendency to attach to particulate matter.
When particulate phosphorus is removed from the wastewater, attached metals are removed also. Cohen and Hannah (1979) suggested alum addition and clarification can remove as much as 43% of the Cd, 91% of the Pb, 25% of the Ni, and 25% of the Zn from the wastewater. Sutherland (1968) noted removals of 16% Se and 97% Ag.

Using alum to remove phosphorus from the wastewater at the MWTP may increase the concentration of heavy metals in the sludge, but it is unlikely that any significant hazard will come from increased sludge metal concentration (Table 7). All current metal levels in the plant's sludge are

<table>
<thead>
<tr>
<th></th>
<th>Influent mg/l</th>
<th>Effluent mg/l</th>
<th>Removed %</th>
<th>Max. Conc. mg/kg dry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cadmium (Cd)</td>
<td>&lt;0.005</td>
<td>&lt;0.005</td>
<td>------</td>
<td>4.94</td>
</tr>
<tr>
<td>Chromium (Cr)</td>
<td>0.21</td>
<td>&lt;0.09</td>
<td>48</td>
<td>42.7</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>0.12</td>
<td>0.025</td>
<td>80</td>
<td>501</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>0.18</td>
<td>&lt;0.05</td>
<td>73</td>
<td>252</td>
</tr>
<tr>
<td>Nickel (Ni)</td>
<td>3.54 *</td>
<td>1.30 *</td>
<td>64</td>
<td>46.5</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>0.12</td>
<td>0.09</td>
<td>25</td>
<td>802</td>
</tr>
</tbody>
</table>

* data highly skewed, possible analysis error

well below the maximum permissible level for application to
land, and alum addition should not increase sludge metal concentrations beyond that level.

For example, sludge lead concentration, which is closest to the maximum allowable level for application to land, would need to be increased by approximately 100% before the level is exceeded. Nearly 80% of the lead is already removed from the wastewater under conventional activated sludge treatment, and the influent concentration of lead seems low enough to preclude an exceptionally high increase in sludge lead concentration.

Although sludge heavy metal concentrations are below maximum permissible levels for land application, the cadmium concentration exceeds the 2.0 ppm EPA limit for unmonitored soil amendments (Federal Register Sept., 1979). Cadmium concentration is the primary basis for deciding whether sludge should be applied to land. Dan Corti a graduate student at the University of Montana, suggested that the MWTP begin monitoring recipient soil pH in light of the relatively high cadmium concentration (Corti, 1985). The MWTP still does not monitor pH of soils receiving sewage sludge. If phosphorus is removed chemically at the MWTP, the integrity of soils receiving sludge may be at a greater risk because of increased sludge cadmium concentration. Soil pH should be monitored with each sludge application to insure the pH remains above 6.5, the minimum pH thought to provide adequate trace metal
soil attenuation (Council for agricultural Science and Technology, 1976).

Cost Analysis

And now for the question everyone seems to be asking: how much is it going to cost? According to Drnevich and LaClair (1976), phosphorus can be removed chemically for $25-50 per million gallons treated. Heim (1980) reported a cost of $45/million gallons. Phosphorus can be removed from wastewater treatment plants in communities with over 10,000 people for less than one cent per capita per day (Jones and Lee, 1986).

Phosphorus can be removed at the MWTP for approximately 1.3 cents per capita per day if a phosphate detergent ban is implemented in conjunction with treatment removal, and the federal government provides monetary assistance (Table 8). Costs were estimated using a variety of sources and some educated guess work. According to the Water Quality Bureau, under the Federal Construction Grants Program, PL-92500, the City of Missoula can obtain assistance for 55% of the construction costs if chemical phosphorus removal is instituted (Scott Anderson, personal communication).

It is imperative that the City of Missoula decide soon on whether to remove phosphorus at the plant. The Reagan administration is determined to eliminate the federal grants program and replace it with a loan program. In 1981, Reagan cut the funding assistance program in half
TABLE 8
COST ESTIMATE FOR CHEMICAL PHOSPHORUS REMOVAL AT THE
MISSOULA WASTEWATER TREATMENT PLANT
(1988 dollars)

### Alum Addition

<table>
<thead>
<tr>
<th></th>
<th>1.0 mg/l TP with out ban</th>
<th>1.0 mg/l TP with ban</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1) Annual Investment with Federal Grant</strong></td>
<td>4,482</td>
<td>4,482</td>
</tr>
<tr>
<td><strong>Annual Operating Costs</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>2) Chemical Costs</strong></td>
<td>166,080</td>
<td>108,870</td>
</tr>
<tr>
<td><strong>3) Labor</strong></td>
<td>8,760</td>
<td>8,760</td>
</tr>
<tr>
<td><strong>4) Electrical</strong></td>
<td>450</td>
<td>450</td>
</tr>
<tr>
<td><strong>5) Sludge Handling</strong></td>
<td>49,522</td>
<td>37,141</td>
</tr>
<tr>
<td><strong>Total Annual Cost</strong></td>
<td>229,294</td>
<td>159,703</td>
</tr>
</tbody>
</table>

**6) Cost Per Capita Per Day (cents)**

|                | 1.8 ($1.86) * | 1.3 ($1.29) |

* cost in parentheses is a monthly cost per household based on 3.3 persons per home.

1) **Capital Investment of 110,700**, estimated from EPA (1976), "Phosphorus Removal Design Manual". Assumes amortization for 20 years at 6 1/8 %, 55% federal assistance.

2) Based on an alum dosage without ban of 100 mg/l, with ban 75 mg/l, alum cost 175/ton (Tom Lind, personal communication).

3) Assumes no new hire, 2 hours per day (12.00/hr).

4) Assumes manual adjustment of alum feed, one 1/2 hp motor on feed facility.

5) based on 35% increase in sludge.

6) based on 33,400 persons on sewer, (MDHES, 1988).
Seeley Lake in a situation similar to Missoula, was advised by the Water Quality Bureau to begin construction now if they wanted assistance from the government (Stromnes, 1988). Over the years, Congress has kept the program alive, but it is unknown how long the funding will remain available.

Fortunately, chemical phosphorus removal with alum is not a capital intensive project. Capital investment cost estimates are based on the plant's capacity of 9.0 million gallons per day and on the assumption that alum would be added to the aeration effluent channel. Included are expenditures for chemical storage, alum feeding, and an allowance for contractor installation, profit, and overhead, as well as an allowance of 20% of the construction cost for engineering consultance. The 1973 costs from above are outlined in the "Phosphorus Removal Design Manual" (EPA, 1976). 1988 costs were determined using an engineering construction cost index from the Survey of Current Business by multiplying the 1973 costs by 2.64.

Chemical costs were determined on a dose-dependent basis with the dosage dependent on the wastewater total phosphorus concentration. Based on self monitoring data from 1985-1987, the total phosphorus concentration was 6.23 mg/l. The alum price of $175/ton was confirmed by Thatcher Co., Missoula, Montana. The actual price may come down if
chemical phosphorus removal is ever instituted at the plant (Tom Lind, personal communication).

Chemical phosphorus removal normally does not require additional staff. Two hours per day is probably sufficient time to carry out the tasks associated strictly with the phosphorus removal process, including adjusting the alum feed and monitoring alum shipments for quality. Mechanical adjustment of the alum feed can be implemented to reduce operator attention, but cost for such a device was not given (EPA, 1976).

Electrical costs would not increase significantly. Depinto (1980) noted that electrical costs for chemical phosphorus removal were very low for plants in New York State, and electrical costs in New York are probably higher than in Montana. Furthermore, only a one half horse power motor needs to be used on the alum feed facility.

The sludge handling cost estimate assumes a 35% increase in sludge generation. According to sewage plant superintendent Tim Hunter, for every pound of BOD removed, approximately 0.75 pounds of sludge is produced. From table 5, the average monthly BOD reduction of 207 mg/l per day in 6 MGD results in the production of approximately 3.94 tons of sludge per day. Assuming a 35% increase in sludge volume (Boyko and Rupke, 1976), an additional 1.4 tons/day will be produced. For anaerobic digestion of all sludge, a $15/ton cost was assumed. This estimate was
based on digestion costs ($5/ton) of a similar plant in 1978, and multiplied by 3 (Heim, 1980). From April to September, sludge is applied to agricultural land, costing an additional $52/ton. During the winter, sludge is dewatered and sent to a private composting company at an additional cost of $114.10/ton (Tim Hunter, personal communication). Increased electrical requirements and trucking expenditures are included in the sludge handling estimate.

A phosphate detergent ban in conjunction with chemical phosphorus removal might save nearly $1,144,200 in chemical costs over a 20 year span. Savings of $247,620 can also be realized in sludge handling costs over the same period assuming the ban would reduce sludge volume by 25%. With these cost savings from a phosphate detergent ban, the resulting sewer fee increase per capita of approximate $1.30/month per person is a small amount when it comes to protecting the Clark Fork River Basin.

It is important to realize that costs for phosphorus removal with alum are directly dependent on the price of alum, and chemical prices will most likely continue to rise. If the plant institutes a chemical phosphorus removal system, there is no turning back. Many plants have decided against chemical phosphorus removal for this reason. Chemical phosphorus removal may mean being at the mercy of rising operational costs.
Implementation Of Chemical Phosphorus Removal

Removing phosphorus chemically at the MWTP in conjunction with a phosphate detergent ban would increase household sewer fees by approximately 22%. Each annexed user of the sewage plant would pay an additional $15.48/year to reduce the effluent total phosphorus level to 1.0 mg/l. Each household currently pays $70.50/year in sewer fees (Joe Adagarie, personal communication).

While city officials consider sewer fees in Missoula inexpensive, an increase in sewer fees of 22% may pose a problem. The City Council in Missoula has the responsibility of deciding whether any endeavor requiring increased resident fees is implemented, and is limited to a 12% increase unless the endeavor in question is mandated by a federal or state agency. The state of Montana and the EPA have not mandated treatment phosphorus removal.

However, removing phosphorus chemically may not be an impossibility. The City Council might be willing to exceed the 12% limit if the project is considered vital. The city council does have members who support the protection of the Clark Fork River. According to the City of Missoula Public Works Director Joe Aldegarie, there was no public opposition to two recent sewer fee increases of 8.5% and 13%, and the council approved the increases. It is not known whether the city council passed the sewer fee increases because the plant was violating BOD and TSS
effluent limit concentrations, but an increase in sewer fees of 22% may be beyond what the council would pass unless the plant is violating permitted discharge levels.
References

Aldegarie, J., City of Missoula Public Works Director, personal communication.

Anderson, S., Montana Water Quality Bureau, personal communication.


Hunter, T., MWTP superintendent. personal communication.


Lind, T., Thatcher Chemical, Missoula, Montana. personal communication.


Process Description

The PhoStrip process is a biochemical process. Phosphorus is removed both chemically and biologically in the activated sludge system. The process takes advantage of the luxury uptake of phosphorus by microorganisms and anaerobiosis for release of phosphorus. A general flow diagram is presented in Figure 6 and is described below.

In the secondary clarifiers of conventional activated sludge systems, microorganisms containing phosphorus settle and become sludge. Normally, some of this sludge is returned to the aeration basins and the rest is sent to digesters. With PhoStrip, 10-30% of the sludge would be channeled to a stripping tank, where anaerobic conditions force the microorganisms to release their protoplastic phosphorus.

After releasing cellular phosphorus, the organisms are sent back to the aeration basins, where the microbes take up more soluble phosphorus. The phosphorus-rich organisms are then sent to the secondary clarifiers were the whole process is repeated (Tetrault, et. al., 1986; Levin, Topol, and Tarnay, 1975). This is the biological step of the PhoStrip process.

Chemically, the phosphorus expelled by the microorganisms in the stripping tank is precipitated with lime. Water from the stripping tank, called supernatant,
FIGURE 6
PROCESS FLOW SCHEMATIC - BIOCHEMICAL PHOSPHORUS REMOVAL
Source: (Heim, 1980).
is sent to a lime reactor clarifier, where soluble phosphate ions react with calcium ions in the presence of hydroxyl ions to form hydroxyapatite (EPA, 1976). Some of the sludge settles in the reactor clarifier, and is wasted. The lime-phosphorus mixture is sent to the primary clarifiers, settles, and the primary sludge is sent to the primary digesters. Once precipitated, hydroxyapatite resists dissolution during digestion.

Quick lime, CaO, is usually used in PhoStrip to precipitate soluble orthophosphate. A saturated solution of lime has a pH of about 12.4 (EPA, 1976). Lime should be handled with care. Workmen should wear protective eyewear because lime dust can cause severe burns. Apparently lime should not be mixed with chemicals which have water of hydration, as there is a possibility of explosion (EPA, 1976). If handled properly, problems can be avoided.

The CaO content in commercial grade lime varies between 76 to 96%. A grade of at least 88% should be used to precipitate phosphorus (EPA, 1976). Lower concentrations often contain high concentrations of unwanted inert materials. Bagged lime should be stored in a dry place, to avoid absorption of moisture. Bulk lime, usually used for wastewater treatment, should be stored in air tight concrete or steel bins having a 60 degree slope at the bin outlet (EPA, 1976).
Effectiveness

The PhoStrip process removes between 85 to 95% of the influent total phosphorus (Drnevich and LaClair, 1975). Typically, PhoStrip produces an effluent with a total phosphorus concentration of 0.5 to 1.0 mg/l, and a soluble phosphorus concentration from 0.1 to 0.5 mg/l (Heim, 1980). PhoStrip is a reliable, resilient process which can be operated with relative ease. Unlike chemical phosphorus removal where influent variations in phosphorus concentration must be monitored and chemical dose adjustments made accordingly, the PhoStrip process can provide continuous phosphorus reduction of greater than 90% in the face of varying influent concentrations (Black, 1984).

The process is completely compatible with the activated sludge system and in fact enhances the overall performance of the activated sludge (Periano, 1977). BOD and suspended solid reduction is enhanced because a more stable, better settling sludge is produced. With lime addition, solids concentration increases by 8 to 20% (EPA, 1976). This produces a sludge which is easily dewatered.

Factors Controlling Phosphorus Removal Performance

Both biological and chemical parameters affect the phosphorus removal effectiveness of the PhoStrip process. Factors that will be discussed include microbial populations, stripper tank detention time, wastewater
alkalinity, and primary clarifier performance.

**Microbial population**

PhoStrip's reliable performance is a result of microbes' ability to respond quickly to environmental changes. The phosphorus absorptive ability of the microbial population affects the phosphorus removal capability of the process. Some microbes have a greater absorptive ability when put through the aerobic-anaerobic staging. For example, the genus *Actinobacter* found in most sewage treatment plants has a superior ability to take up and release phosphorus (Heim, 1980). Even under normal activated sludge operating conditions, phosphorus removal of greater than 85% is attainable (Black, 1984). Most microorganisms take up luxury amounts of phosphorus apparently to avoid harm in case nutritionally poor environments are encountered (Tetrault et. al., 1986).

**Stripper tank detention time**

The length of time microorganisms are held in the stripper tank under anaerobic conditions affects phosphorus removal performance. The rate of phosphorus release per unit mass of organism is a function of the duration of the anaerobic period (Heim, 1980). An overly long anaerobic period relative to the aerobic period can cause microbes to cease phosphorus uptake. The correct length of the anaerobic period depends on a host of factors. Tetrault,
et al. (1986) suggested the time required in the stripper tank ranges from 5 to 20 hours, and that preliminary adjustments should be encouraged to analyze performance under different detention scenarios. The stripper detention time can be adjusted by altering the sludge blanket depth in the stripper tank (Tetrault, et. al., 1986). In addition, Tetrault and associates mentioned that increasing the detention time in the stripper tank can promote phosphorus removal performance. Nitrification in the activated sludge, which hinders phosphorus removal performance, can be hindered by increasing the stripper tank detention time.

Phosphorus removal can also be enhanced by removing phosphorus-deficient sludge from the bottom of the stripper tank and recycling the sludge to the stripper infeed (Tetrault, et. al. 1986). Recycling the sludge forces the microbes to go through the process twice, and apparently more phosphorus is released. Phosphorus reduction to approximately 0.05 effluent total phosphorus concentration can be achieved by this optional recycling process (Figure 6).

**Wastewater Alkalinity**

The wastewater alkalinity of the stripper supernatant determines the lime dosage required for phosphorus precipitation. Phosphorus removal with lime is a pH dependent reaction. Hydroxyapatite does not begin chemical
formation until the pH is raised to approximately 9.0 (EPA, 1976). As the pH is raised above 9.0, more precipitant is formed. In general, a lime dosage of 150 mg/l is enough to raise the pH above 9.0. (EPA, 1976). In Tetrault, et. al., (1986), treatment plants were removing more than 90% total phosphorus with lime dosages of 100 mg/l. The PhoStrip process is so efficient, that rarely will the operator need to raise the pH above 9.5 to remove phosphorus effectively (Heim, 1980).

Primary clarifier performance

Any time phosphorus is removed by the formation of a precipitated floc, settling of some kind ultimately removes the phosphorus. With PhoStrip, the primary clarifiers provide the mechanism to do so. Their performance is vital to effective phosphorus removal. Primary clarifiers at the MWTP are considered highly efficient (T. Hunter, personal communication).

Potential Problems With Biochemical Phosphorus Removal

Operationally, the PhoStrip process poses no threat to the activated sludge system at Missoula. Because it chemically treats only 10-30% of the influent flow, the process produces only half as much additional sludge as alum addition (Heim, 1980; Levin, Topol, and Tarnay, 1975; Black, 1984). Assuming an increase in sludge generation of 35% with alum addition, the anaerobic digesters at the
plant should be able handle the 16% increase in sludge by PhoStrip with their current capacity. In addition to creating more sludge, lime also increases sludge solids concentration which may allow operators flexibility in avoiding digestion problems.

Other wastewater parameters should not be affected. No anions such as sulfate are added to the wastewater, and only a small increase in sludge metal content occurs using the PhoStrip process (Levin, Topol, and Tarnay, 1976). The relatively small amount of lime added is channeled to the primary clarifiers, which should not adversely affect biological activities in the aeration unit and anaerobic digestion of the activated sludge system (EPA, 1976; Heim, 1980).

Although PhoStrip is reliable, personnel may need to be trained or hired at the MWTP to run the system effectively. Only during the first few months would consulting and training be necessary. Apparently, once the PhoStrip process has been fine-tuned operationally, the system can endure major operational mishaps without appreciably affecting effluent quality (Drnevich and LaClair, 1976). Personnel would need to be available to monitor lime quality. If lime is purchased from Thatcher Co. in Missoula, this should not be a problem. According to Tom Lind, a Thatcher employee, CaO content of their lime is approximately 94%.
Construction problems may arise. According to Joe Aldegarie the Missoula Public Works Director, underground pipes at the plant may hinder construction. The Public Works Department would need to look into this matter.

Cost Analysis

A cost estimate associated with biochemical phosphorus removal at the MWTP can be seen in Table 9. Heim (1980), estimated that phosphorus can be removed using PhoStrip for $90,726/year without federal assistance. Levin, Topol, Tarnay (1976) estimated it would cost approximately $72,800/year also without federal assistance.

With federal assistance, the MWTP can remove phosphorus biochemically for approximately $84,165/year. According to Scott Anderson of the Montana Water Quality Bureau, the federal government would compensate 75% of all capital costs associated with instituting biochemical phosphorus removal at the MWTP. Capital costs are based on instituting the process at the plant capacity of 9.0 million gallons a day. Annual capital costs were calculated assuming this level of federal assistance and amortization for a twenty year period at 6 1/8 %. A capital cost breakdown can be seen in Appendix B.

The chemical cost estimate was made assuming 15% of the current average flow of 6.1 MGD would be treated with lime. Wastewater alkalinity is not monitored at the MWTP. In light of this, a conservative lime dosage estimate of 200
### TABLE 9
COST ESTIMATE FOR BIOCHEMICAL PHOSPHORUS REMOVAL AT THE MISSOULA WASTEWATER TREATMENT PLANT 1988 DOLLARS

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Annual Investment with Federal Grant</td>
<td>22,434</td>
</tr>
<tr>
<td>2) Chemical Cost</td>
<td>29,890</td>
</tr>
<tr>
<td>3) Electrical Cost</td>
<td>1,700</td>
</tr>
<tr>
<td>4) Labor</td>
<td>5,380</td>
</tr>
<tr>
<td>5) Sludge Handling</td>
<td>24,761</td>
</tr>
<tr>
<td><strong>Total Annual Cost</strong></td>
<td><strong>84,165</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6) Cost Per Capita</td>
<td>.7 ($ .68)</td>
</tr>
</tbody>
</table>

* cost in parentheses is a monthly cost per household assuming 3.3 persons per home.

1) cost breakdown is outlined in Appendix B. Assumes amortization for 20 years at 6 1/8%, 75% federal assistance.

2) based on 15% influent flow, lime dose of 200 mg/l, lime cost of 120/ton (Tom Lind, personal communication).

3) estimated from Levin, Topol, and Tarnay (1975).

4) based on 20,000 consultance cost, 1 hour per day ($12.00 per hour).

5) based on a 17% increase in sludge generated.

6) assumes 33,400 people on sewer.
mg/l was chosen. A lime cost of $120/bulk ton delivered was assumed. Actual bulk lime cost may come down if the plant institutes biochemical phosphorus treatment (Tom Lind, personal communication).

Additional labor costs were estimated by allocating $20,000 for initial operational consulting expenditures, paid over the 20 year time span. Once the process is fine-tuned, the plant personnel's main function would be to monitor incoming shipments for quality. Minor operational adjustments may be needed periodically. One hour per day at $12.00 per hour seems sufficient to cover these costs.

Levin, Topol, and Tarnay (1975) reported an electrical cost increase of $0.75 per million gallons at a 10 MGD plant. This estimate was used to calculate an electrical cost increase at the MWTP. It was assumed electrical costs have not risen significantly since 1975. This may be an underestimate of increased electrical expenditures; but only two new large pumps (pumping sludge between the aeration basins, stripper tank and back) would use additional electricity. A one-half horse power pump can be used to add the lime.

Costs for increased sludge handling were accounted for under the sludge handling estimate. Compared to alum addition, the PhoStrip process generates half the additional sludge volume (Black, 1984; Levin, Topol, and Tarnay, 1975). Costs were determined by taking half the
sludge handling cost associated with alum addition without a phosphate detergent ban. This cost may be an overestimate. Lime addition is known to produce a sludge that is much easier to handle (EPA, 1976). The same sludge handling cost (per ton) used for alum addition was used here (see Chemical Precipitation-Cost Analysis).

Removing phosphorus with PhoStrip is a much more capital intensive project than alum addition, but the federal government is willing to pay more to see PhoStrip instituted. The government hopes to influence treatment plant upgrading by supporting biochemical phosphorus removal. Compared to chemical phosphorus removal, cost on a per capita basis is significantly lower for biochemical phosphorus removal. Because less wastewater is chemically treated, lower chemical costs are realized. Unlike chemical precipitation, the PhoStrip process would not put the City of Missoula disproportionately at the mercy of rising chemical costs. From the standpoint of long term financial planning, the process makes good sense, but the City of Missoula would need to commit more funds up front.

Implementation Of Biochemical Phosphorus Removal

Removing phosphorus biochemically at the MWTP would increase household sewer fees by approximately 12%. Each household would need to pay an additional $8.16/year in additional sewer fees. A 12% increase in sewer fees can be passed by the Missoula City Council without federal or
state mandate. A discussion of parameters affecting the
council's authority pertaining to increased residential
fees is found in a section identical to this one under
"Chemical Phosphorus Removal".
References


Lind, T., Thatcher Chemical, Missoula, Montana. personal communication.


LAND APPLICATION OF WASTEWATER

Process Description

Municipalities have applied wastewater to land for over 100 years. In 1981, there were approximately 320 land application facilities in the U.S. (EPA, 1984). Conceptually, land application is an attempt to use the earth as a filter. Wastewater is applied to land in an effort to cleanse it of various pollutants. Filtering downward under the force of gravity, pollutants become attenuated in the soil matrix. But a land application system is not an industrial seepage bed, nor a simple application of wastewater to land. It is a complex, well-managed, closely monitored system able to provide treatment equal to and often better than conventional advanced wastewater treatment.

Land application systems have been given various names in the literature. Common names applied to these systems include slow rate irrigation, rapid infiltration, and overland flow. Table 10 lists the design and operation features of land treatment processes, while Table 11 summarizes site characteristics. Slow rate irrigation systems are similar to conventional agricultural systems, except that in slow rate facilities the priority is wastewater renovation, not crop production. Slow rate systems are by far the most commonly used and can be
TABLE 10
COMPARISON OF DESIGN FEATURES FOR LAND TREATMENT SYSTEMS
Source: (Sheaffer, Nagelvoort, and Moser, 1984).

<table>
<thead>
<tr>
<th>Feature</th>
<th>Slow Rate</th>
<th>Rapid Infiltration</th>
<th>Overland Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application techniques</td>
<td>Sprinkler or surface(^a)</td>
<td>Usually surface</td>
<td>Sprinkler or surface</td>
</tr>
<tr>
<td>Annual application rate (m)</td>
<td>0.6 - 6.0</td>
<td>6.0 - 170</td>
<td>3 - 21</td>
</tr>
<tr>
<td>Field area required (^b) (ha)</td>
<td>22 - 220</td>
<td>0.8 - 22</td>
<td>6.4 - 45</td>
</tr>
<tr>
<td>Typical weekly application rate (cm)</td>
<td>1.3 - 10</td>
<td>10 - 305</td>
<td>6 - 15(^c)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>15 - 40(^d)</td>
</tr>
<tr>
<td>Minimum preapplication treatment provided in United States</td>
<td>Primary sedimentation(^e)</td>
<td>Primary sedimentation</td>
<td>Screening and grit removal</td>
</tr>
<tr>
<td>Disposition of applied wastewater</td>
<td>Evapotranspiration and percolation</td>
<td>Mainly percolation</td>
<td>Surface runoff and evapotranspiration with some percolation</td>
</tr>
<tr>
<td>Surface discharge if drainage recovery</td>
<td>Required</td>
<td>Surface discharge if drainage recovery</td>
<td>Optional</td>
</tr>
<tr>
<td>Need for vegetation</td>
<td>Optional</td>
<td>Optional</td>
<td>Required</td>
</tr>
</tbody>
</table>

\(^a\) Includes ridge-and-furrow and border strip.

\(^b\) Field area in acres not including buffer area, roads, or ditches for 1 mgd (43.8 liter/sec) flow.

\(^c\) Range for application of screened wastewater.

\(^d\) Range for application of lagoon and secondary effluent.

\(^e\) Depends on the use of the effluent and the type of crop.

expected to remove oxygen-demanding materials, nutrients, heavy metals, and pathogens.

Rapid infiltration systems are designed on soils of high permeability. They are used to treat larger volumes
of wastewater and are capable of removing significant amounts of BOD, suspended solids, heavy metals, and phosphorus.

Overland flow facilities remove pollutants as the wastewater flows across the land surface. A soil of low infiltration capacity is desired, and applications are carefully timed. Overland flow systems are capable of wastewater renovation equal to the others except phosphorus is not effectively removed.

<table>
<thead>
<tr>
<th>Principal Processes</th>
<th>Slow Rate</th>
<th>Rapid Infiltration</th>
<th>Overland Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope</td>
<td>Less than 20% on cultivated land; less than 40% on noncultivated land</td>
<td>Not critical; excessive slopes require much earthwork</td>
<td>Finish slopes 2 - 8%</td>
</tr>
<tr>
<td>Soil permeability</td>
<td>Moderately slow to moderately rapid</td>
<td>Rapid (sands, loamy sands)</td>
<td>Slow (clays, silts, and soils with impermeable barriers</td>
</tr>
<tr>
<td>Depth to groundwater</td>
<td>0.6 - 0.9 m (minimum)</td>
<td>3 m (lesser depths are acceptable where underdrainage is provided)</td>
<td>Not critical</td>
</tr>
<tr>
<td>Climatic restrictions</td>
<td>Storage often needed for cold weather and precipitation</td>
<td>None (possibly modify operation in cold weather)</td>
<td>Storage often needed for cold weather</td>
</tr>
</tbody>
</table>

**TABLE 11**

COMPARISON OF SITE CHARACTERISTICS LAND TREATMENT SYSTEMS

Source: (Sheaffer, Nagelvoort, and Moser, 1984)
**Effectiveness**

Land application systems can provide exceptional phosphorus removal (EPA, 1978). For over 88 years, the municipality of Calumet, Michigan has used a slow rate irrigation facility with 89-97% influent total phosphorus removal (Scheaffer, et. al., 1984). In Dickinson, North Dakota, a slow rate irrigation system removes 90% of the influent total phosphorus (Thomas, 1979). Camarillo, Texas, has been able to reduce both soluble and total phosphorus levels by 90% with a rapid infiltration system. Of the nine land treatment systems studied (EPA, 1984), all reduced total phosphorus levels to 1.0 mg/l.

**Factors Controlling Phosphorus Removal Performance**

**The soil**

Physical, chemical, and biological processes all play a role in the attenuation of phosphorus in soil. Physically, ground water dispersion controls the spread of phosphorus as it moves downward through the soil profile. Ground water advection, or the flow of water through soil, is controlled by the flow path tortuosity and the effective porosity of the unsaturated zone.

Think of it this way: Water moves under the force of gravity through soil's interconnected air spaces. The effective porosity is a term used to describe how interconnected the air spaces are. Tortuosity is a measure
of how winding the interconnected air spaces are. Clays
have very small, tortuous openings. On the other hand,
gravels have large, nontortuous flow paths. Depending on
the physical properties of the soil, phosphorus may become
attenuated, or pass through to the groundwater. Highly
tortuous soils with a small effective porosity will trap
more phosphorus.

Physical processes may control the spread of phosphorus
through soil, but chemical processes keep the phosphorus in
the soil. The capacity for individual soils to remove
phosphorus largely depends on the presence of organic
matter, clay, and iron and aluminum oxides in soil (EPA,
1981; Duffer, et al., 1978). Wastewater phosphorus
applied to land adsorbs to these materials in the soil.
Once sorbed, a slower reaction precipitates or mineralizes
phosphate as inorganic compounds into the soil matrix
(Duffer, et al., 1978). The initial adsorption process
will limit the rate of phosphorus attenuation until soil
adsorption sites are saturated. After saturation, further
phosphorus removal will be controlled by the slower rate of
precipitation or mineralization. This is why land
treatment systems show high phosphorus attenuation
initially, but as the system becomes older the rate of
phosphorus retention drops (Leach, 1979).

The thickness of the soil profile affects phosphorus
removal. A deep soil has a greater number of adsorption
sites. The more soil that wastewater drains through, the more adsorption sites encountered. For the most part, phosphorus is held within the top 6 to 12 inches of the soil (Leach, 1979), but layers well beneath the surface may provide significant phosphorus attenuation depending on the geomorphology of the region (Ellis, 1974). Consequently, the water table depth affects phosphorus attenuation.

Microbial populations affect phosphorus attenuation in soil as well. Microbes absorb phosphorus to live, but they also indirectly affect phosphorus retention by maintaining the infiltration capacity of soil. Microorganisms degrade excessive amounts of organic matter which otherwise would clog pore spaces at and below the surface.

**Wastewater loading rate**

The rate at which wastewater is applied can affect phosphorus removal. This is especially true with Rapid Infiltration systems. Tofflemire and Chen (1977) showed that sandy soils of Rapid Infiltration systems are susceptible to phosphorus breakthrough because of large wastewater applications. Adsorption sites on sandy soils can easily become saturated, losing their ability to hold phosphorus.

Operators can avoid this by applying wastewater intermittently. For example, wastewater can be applied on a two weeks on / two weeks off schedule. Intermittent loading may regenerate phosphorus adsorption sites (Sauhney
and Starr, 1977; Jones and Lee, 1979). Resting land application systems also maintains the infiltration capacity of the soil (Leach, 1979). Short inundations of wastewater with longer drying times allow the soil to become aerated, enhancing decomposition and desiccation of organic material as well as keeping a check on microbial populations. Microbial populations are important for maintaining infiltration capacity, but too many can clog pores.

**Vegetation**

To maximize phosphorus removal, vegetation should be grown. All estimates suggest that vegetation will remove approximately 50% of all the phosphorus applied to land (Leach, 1979; Duffer, et. al. 1978; Hershaft and Truett, 1981; Scheaffer, et. al., 1984). Virtually any type of vegetation can be used, including cash crops and pine forests, but perennial grasses seem to work the best (Kardos and Sopper, 1974). Vegetation also helps maintain soil infiltration capacity and reduces erosion.

**Climate**

Rapid Infiltration Systems are the only type of land application system that is inundated with wastewater during the winter. Overland Flow and Slow Rate Irrigation systems may be used by municipalities in cold weather climates, but wastewater is stored during the winter. Rapid Infiltration
Systems can be used during the winter because the wastewater ice layer insulates the ground from the cold, and ground water rarely freezes. As the wastewater infiltrates the soil, the water level drops breaking up the ice. When the wastewater is re-applied, it reaches the soil surface and infiltrates.

Potential Problems With Land Application Of MWTP Effluent

There are few environmental problems with applying the MWTP effluent to land. In fact, land application systems do far more than remove phosphorus. BOD, suspended solids, and pathogen removal of greater than 95% can be expected routinely (Duffer, et. al., 1978; Thomas, 1979; Sheaffer, et. al., 1984; Hershaft and Truett, 1981). Most heavy metals will be retained within the clay and organic fractions of soil (Ellis, 1974; Tofflemire and Chen, 1977). Heavy metal adsorption is pH dependent. If soil pH is greater than 7.0, as expected after wastewater application, heavy metals readily precipitate as a hydroxide or a carbonate (Elliott, Liberati, and Huang, 1986). Minimal heavy metal retention can be expected in soils with an organic matter content below 25 g/kg (Tofflemire and Chen, 1977). Effluent from wastewater treatment plants contain organic matter which becomes incorporated in soil, facilitating metal attenuation.

In Hershaft and Truett (1981), six land application systems were examined for impacts on the environment.
Metals did not concentrate in plants where wastewater was applied to soil. Metal concentrations in ground water were always below drinking water standards. For over 17 years, the receiving ground water associated with the system in Dickinson, North Dakota, has exhibited Zn, Cu, and Cr concentrations below drinking water standards (Thomas, 1979). At the same system, Cd, Pb, and Ag have never been found in crops or ground water supplies.

The EPA claims that crops and groundwater supplies will not pose a threat to the environment or humans if the maximum permissible metal levels for land application are followed (EPA, 1979). The EPA does warn that extremely sandy soils should be avoided where industrial dischargers make up a significant amount of the wastewater generated.

Soils in Missoula valley

The Grantsdale loam soil in the Missoula Valley is thought to provide poor filtering capacity. Verhay (1987), said that soils within the valley consist mainly of sand and gravel, and that some areas should not be subjected to heavy chemical addition of any type. A description of soils in the Missoula Valley can be found in Appendix C.

In addition, a Rapid Infiltration system used to treat waste at the Frenchtown pulp mill eventually ceased to work after years of use, and was abandoned. Apparently, operators had difficulty maintaining the infiltration capacity of the soil. Intermittent loading of wastewater
was practiced, but the system continued to fail.

Heavy metals

Although the effluent from the MWTP contains very low concentrations of metals, BOD, and suspended solids (Tables 5 and 7), more should be known about the heavy metals if effluent is applied to land around Missoula. According to the Council for Agricultural Science and Technology (1976), copper, nickel, cadmium, and zinc pose potential serious hazards. Each is described in more detail below. Data is from Jeffus (1979) and Council for Agricultural Science and Technology (1976).

Copper

Copper is found in most soils at a concentration ranging from 10 to 80 parts per million (ppm). Plants need copper to survive, but at high concentrations copper toxicity can occur. Normal concentrations in plants range from 5 to 20 ppm. In soil, copper adsorbs to organic matter and hydrous oxides of manganese and iron. Copper accumulates in the roots with very little translocating to the foliage. Compared to zinc, copper is considered approximately twice as toxic to plants.

Copper is also toxic to animals at high concentrations. Apparently sheep are the most susceptible to copper toxicity, followed by cattle, pigs, and poultry. The main concern is that copper may accumulate in soil over a period of years and become concentrated in plants at toxic levels.
In turn, livestock or even humans may be affected.

**Nickel**

Nickel is found in all plants, soils, and water. In soils, nickel is found adsorbed to organic matter, manganese, and iron hydrous oxides with levels ranging from 10 to 100 ppm. Nickel has no known function in plants and is toxic at concentrations greater than 50 ppm. Plants on acidic soils seem to be the most vulnerable to nickel toxicity. Nickel is not considered highly toxic to animals.

**Cadmium**

Cadmium is found throughout the environment. Soil concentrations range from 0.01 to 7 ppm. Cadmium is taken up through the roots by plants and is translocated to the foliage. Soil chemistry of cadmium is not well understood, but cadmium retention in soil appears to be influenced by organic matter, clay content and type, soil pH and redox potential.

Cadmium is toxic to plants and is a cumulative poison to man and animals. For this reason, cadmium sludge concentration is the primary basis for deciding whether or not a sludge is acceptable for land application. Applications of cadmium should be closely monitored. Because cadmium is the heavy metal most likely to have an impact on food produced on land treatment systems, the EPA suggests investigating cadmium removal prior to treatment.
A summary of metal recovery techniques can be found in Sittig (1975).

**Zinc**

Zinc is mainly used as a protectant of metals to prevent corrosion. It is a constituent of many household items such as antiseptics, insecticides, and linoleum. Zinc is an essential nutritional trace element but can cause toxicity to plants and animals at high concentrations. Compared to other trace elements, zinc is most soluble in acidic soils and has been used as a standard for plant toxicity. Zinc is not likely to be a major concern in the disposal of effluent to land, especially if soil pH is kept above 6.5.

The Council for Agricultural Science and Technology (CAST) has recommended the following management procedures to ensure minimal heavy metal toxicity:

--- Maintain the soil pH above 6.5.
--- Grow crops which accumulate relatively low concentrations of cadmium. Plant types are described in CAST (1976).
--- Make only small annual applications of cadmium.
--- Grow non edible crops.

**The nitrate problem**

Nitrate exceeds drinking water standards in ground waters of many land application systems (Hershaft and
Nitrogen conversions in the soil produce water soluble nitrate, which ultimately leaches downward to pollute ground water supplies. When wastewater is applied, ammonium and organic nitrogen accumulate in the soil. Eventually the ammonium and organic nitrogen are converted to nitrate, nitrite, nitrous oxide, or nitrogen gas, which then leave the soil. The rate of nitrogen's conversion and ultimate fate is influenced by pH, temperature, aeration, moisture availability, and the presence of microorganisms.

Nitrate leaching through soil may be controlled. The idea is to transform ammonium and nitrate to organic nitrogen by supplying oxygen and carbon to soil. Oxygen limits the conversion of ammonium to organic nitrogen (Ellis, 1974), and operators may promote this reaction by staggering wastewater applications. Under anaerobic conditions, when the system is inundated, denitrifying bacteria use nitrate as an electron acceptor. In this reaction 3.2 grams of carbon are required for each gram of nitrogen (Duffer, et. al., 1978). Duffer, et. al. (1978) realized by changing the carbon-to-nitrogen ratio, nitrate removal could be enhanced. Using wastewater with a carbon-to-nitrogen ratio of 5:1, he reported a 90% removal of nitrate. At a ratio of 3:1, only 60% of the nitrate was removed. If effluent from the MWTP is applied to land, operators should be able to control nitrate leaching by adding more carbon (glucose) to the wastewater and
Personnel shortages

If a land application system is used to remove phosphorus, additional personnel may need to be hired for wastewater application duties, bookkeeping, etc. Although secondary treatment is the maximum treatment required for land application, more soil monitoring would be required. A land application system must not be used with the waste disposal approach of "out of sight out of mind".

Cost Analysis

At this time, it is not feasible to estimate the cost of implementing a land application system. Too many factors need to be considered. Specialists in soils, hydrology, geology, botany, toxicology as well as many other fields would need to be consulted. Land would need to be purchased, since the City owns very little land near the plant (Tim Hunter, personal communication). A piping system as well as a storage facility may need to be constructed. The site would have to be managed. Because the soils in Missoula Valley are so permeable, it may be necessary to install underdrains to collect the renovated water.

How much the above would cost is anybody's guess at this time. Scheaffer, et. al. (1984) reported operating costs for Muskegon, Michigan at 17 cents/1000 gallons. Applying this to the MWTP, the operating cost annually
would be approximately $380,000. Cost estimates on land application systems in the literature are misleading. Time and time again the literature suggests that land treatment costs are comparable to conventional treatment costs, but costs are comparable only when starting from scratch. That is, if a town wants to institute sewage treatment, the cost of instituting a conventional sewage treatment plant with phosphorus removal is comparable to the cost of instituting a land treatment system.

If a land application system is used to treat effluent from the MWTP, there are a few things that may be attempted to alleviate some of the construction costs. Agricultural irrigation canals near the plant might be used to provide the piping and storage of wastewater. To avoid costly storage of wastewater, the land application system could be designed with different parcels of land being flooded at different times. A simple valve system along the pipeline could be constructed, and valves could control which parcels of land are flooded with wastewater.
References


Hunter, T., personal communication.


CONCLUSION

The eutrophication problems in the Clark Fork River Basin will not go away unless phosphorus loadings are curtailed. The Clark Fork River/Lake Pend Oreille ecosystem needs our help now. Signs of gross neglect have been identified in time to slow and possibly reverse eutrophication in the basin.

There is enough evidence to warrant controlling phosphorus at the MWTP. The MWTP, like most wastewater treatment plants, has a high potential for accelerating eutrophication. Periphyton and algal assay studies in the lower Clark Fork, show that effluent from the MWTP is degrading the Clark Fork River Basin.

I would recommend at this time the City of Missoula adopt a phosphate detergent ban. A phosphate detergent ban would reduce the soluble phosphorus load from the MWTP by 25%. Economically, the city would not need to spend anything to adopt a ban. Consumer cost would not increase significantly because laundering performance and cost for nonphosphate detergents are comparable to phosphate types. Environmentally, not only would the ban protect the river, but phosphorus-user reduction of any type will alleviate the apparent shortage of phosphate rock worldwide. In addition, if phosphorus is chemically removed at the plant, a phosphate detergent ban would reduce the operational costs associated with phosphorus precipitating chemicals.
and sludge handling. Most important, is that a phosphate detergent ban would set a precedent. It would be a clear sign that the City of Missoula is concerned about the quality of the Clark Fork Basin. It would be the foundation for which future attempts to reduce phosphorus loading form the MWTP and Missoula County could be based.

In addition, House Bill 711, passed during Flathead and Lake county’s battle to adopt a phosphate detergent ban, has opened the door for the City of Missoula to follow suit. All the City of Missoula needs to do is pass an ordinance to remove phosphates from detergents. Because many rural merchants receive detergents directly from Missoula merchants, if Missoula adopts a phosphate detergent ban, the County also would be adopting a ban. This would avoid lengthy legislative procedures necessary for adopting a phosphate detergent ban on a countywide basis under House Bill 711.

Total phosphorus can be chemically removed to a level of 1.0 mg/l at the MWTP at a cost of approximately 1.3 cents per capita per day ($1.68 a month for a family of four). Capital costs are minimal, but operational costs are high and may increase in the future. Furthermore, additional sludge will be generated using chemicals to remove phosphorus, possibly overloading the anaerobic digesters at the MWTP. Sludge metal concentrations would most likely increase, however, the increase should not
significantly effect current sludge handling processes or degrade the environment.

Total phosphorus can be biochemically removed to a level of 1.0 mg/l at the MWTP for approximately 0.6 cents per capita per day ($0.82 per month for a family of four). Capital costs are significant, but operational costs are not. Once fine-tuned, the process can remove phosphorus effectively on a continual basis. This process will not increase sludge metal concentrations significantly, may provide a better settling sludge, and poses no measurable threat to the environment.

Applying MWTP effluent to land to remove phosphorus needs to be looked into further. Land application systems can remove phosphorus effectively. Subjecting soils in the Missoula Valley to over 6 MGD may be unpopular, but if designed and managed properly the integrity of ground water and soils can be maintained. Proper design and management might require personnel increases at the MWTP. How much a land application system would cost is unknown at this time, but costs may be significant.

Far too often action is taken in vain to clean up our pollution. We cannot let this happen to the Clark Fork River Basin. The added expense of phosphorus removal is necessary. The degradation of the Clark Fork River Basin jeopardizes the economic gains from fishing, water sports, irrigation, and water supply, the spiritual closeness the
lake and river have for some, and the cultural significance this resource has for us all. The quality of life for the people who call western Montana and northern Idaho home is at stake, and the time to act is now.
EPILOGUE

On May 17th, 1988, the Missoula City Council unanimously passed a motion to begin procedures for adopting a phosphate detergent ban within a 4.5 mile radius of the city proper. By January 1, 1989, supermarket shelves may be completely stocked with detergents containing no phosphorus, and phosphorus load reduction at the MWTP may become a reality.

The City of Missoula has also agreed to limit the sewage plant's monthly phosphorus load to 375 pounds per day. It appears the city will abide by the nondegradation policy set in 1986, in which limits are based on the actual phosphorus load of 1982. If a phosphate ban is eventually adopted, the city should be able to continue with annexation of unsewered homes until approximately the year 2000, without violating the phosphorus effluent limit. Whether the city will wait until the limit is approached before removing phosphorus at the plant is unknown. However, the city has allocated $15,000 to begin studies on the feasibility of using a land application system to treat the plant's effluent. The Clark Fork River/Lake Pend Oreille ecosystem will directly benefit by the city's actions. Missoula officials should be commended.

More needs to be done to restore the Clark Fork Basin. Nonpoint phosphorus loading should be curtailed. Phosphorus inputs from residential septic systems around
Lake Pend Oreille may contribute significant amounts of phosphorus to the lake, and should be reduced. We all can do something to alleviate the apparent eutrophication problem in the Clark Fork Basin. The future of this ecosystem is now in our hands.
APPENDIX A

Information on Phosphate - Free Detergents.

SUPPLIERS OF PHOSPHATE - FREE DETERGENTS

--- Columbia Chemicals 442-6300
  Jim Hodges and Tom Joehler - owners
  Helena, Montana

--- Economics Laboratory
  St. Paul Minnesota

--- Far Best
  Elk Grove Village, Illinois

--- Service Master
  Downers Grove, Illinois
PHOSPHORUS CONTENT

RESULTS OF A SHELF SURVEY OF TWO STORES IN MISSOULA, MONTANA: 5/13/88

By Carolyn Hathaway and Penny Klaphake, members, Missoula League of Women Voters

RESULTS: Phosphorus-FREE (or less than .5% phosphorus) products include

(a) 10 of 26 granular laundry products recorded;
(b) all 15 liquid laundry products recorded;
(c) 6 of 8 granular bleaches and bleach substitutes recorded;
(d) all liquid pre-washes (5), liquid bleaches (6), liquid fabric softeners (10), and liquid dishwashing detergents (14 - for washing by hand) were either phosphorus-free or noncommittal;
(e) 20 of 21 general household cleaners contained no phosphorus (17) or were noncommittal (3); only Spic and Span contained phosphorus - 7.6%;
(f) body soap bars listed no phosphate compounds as ingredients; one (Vel) stated "no phosphates."

Calgon, the one granular water softener available, contained phosphates (but no % given) in Store A, but none in Store B. The non-phosphate box was cheaper.

Dishwasher detergents all contained phosphorus, from 7.1 - 8.7% in granular detergents, to 4.0 - 6.3% in liquid detergents.

CONCLUSIONS

1. Consumers have a wide variety of detergents and cleaners to choose from that are phosphorus-free yet comparable in price to, or cheaper than, those with phosphorus.

2. The exception to the above are dishwasher detergents, since none available at either store were phosphorus-free. However, liquid dishwasher detergents were lower in phosphorus content. For example, liquid Sunlight had less than half the phosphorus of granular Sunlight, and was also cheaper.

Attached: Survey of phosphorus content and cost per ounce of granular and liquid laundry products, granular bleaches and bleach substitutes, granular and liquid dishwasher detergents.
Note: * below refers to a concentrated detergent with phosphorus % and cost adjusted for comparative purposes.

<table>
<thead>
<tr>
<th>Granular Laundry Products</th>
<th>Store A</th>
<th>Store B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albertson's Heavy Duty</td>
<td>8.2/.028</td>
<td>N/A</td>
</tr>
<tr>
<td>All</td>
<td>0/.052</td>
<td>0/.05</td>
</tr>
<tr>
<td>Arm and Hammer</td>
<td>0/.04</td>
<td>0/.039</td>
</tr>
<tr>
<td>Ajax</td>
<td>0/.047</td>
<td>0/.041</td>
</tr>
<tr>
<td>Bold</td>
<td>7.1/.067</td>
<td>N/A</td>
</tr>
<tr>
<td>Bold 3</td>
<td>7.1/.039</td>
<td>7.1/.041</td>
</tr>
<tr>
<td>Cheer</td>
<td>6.4/.058</td>
<td>6.4/.058</td>
</tr>
<tr>
<td>Dash Lemon Fresh</td>
<td>6.4/.052</td>
<td>6.4/.05</td>
</tr>
<tr>
<td>Dreft</td>
<td>N/A</td>
<td>8.2/.065</td>
</tr>
<tr>
<td>Fab One Shot Packets</td>
<td>12.1/.135</td>
<td>12.1/.135</td>
</tr>
<tr>
<td>(for washer and dryer)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fresh Start *</td>
<td>7.4/.07</td>
<td>7.4/.062</td>
</tr>
<tr>
<td>Gain</td>
<td>7.1/.054</td>
<td>7.1/.054</td>
</tr>
<tr>
<td>Generic</td>
<td>0/.028</td>
<td>nocommit/0.024</td>
</tr>
<tr>
<td>Generic Low Suds</td>
<td>N/A</td>
<td>0/.012</td>
</tr>
<tr>
<td>Ivory Snow</td>
<td>0/.093</td>
<td>0/.085</td>
</tr>
<tr>
<td>Janet Lee</td>
<td>0/.024</td>
<td>N/A</td>
</tr>
<tr>
<td>Oxydol</td>
<td>8.6/.067</td>
<td>8.6/.058</td>
</tr>
<tr>
<td>Parade</td>
<td>N/A</td>
<td>0/.025</td>
</tr>
<tr>
<td>Purex</td>
<td>0/.041</td>
<td>0/.027</td>
</tr>
<tr>
<td>Sun</td>
<td>0/.024</td>
<td>0/.022</td>
</tr>
<tr>
<td>Surf</td>
<td>7.5/.064</td>
<td>7.5/.037</td>
</tr>
<tr>
<td>Tide</td>
<td>9.8/.052</td>
<td>9.8/.058</td>
</tr>
<tr>
<td>Trend</td>
<td>0/.038</td>
<td>0/.031</td>
</tr>
<tr>
<td>White King</td>
<td>% not given/0.57</td>
<td>% not given/0.053</td>
</tr>
</tbody>
</table>
Granular Laundry Products con't.

<table>
<thead>
<tr>
<th></th>
<th>% Phosphorus/Cost per ounce:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Store A</td>
</tr>
<tr>
<td>White King D</td>
<td>N/A</td>
</tr>
<tr>
<td>Wintree *</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Liquid Laundry Products

<table>
<thead>
<tr>
<th></th>
<th>% Phosphorus/Cost per ounce:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Store A</td>
</tr>
<tr>
<td>Albertson's Heavy Duty</td>
<td>0/$0.038</td>
</tr>
<tr>
<td>All</td>
<td>0/$0.039</td>
</tr>
<tr>
<td>Arm and Hammer</td>
<td>0/$0.046</td>
</tr>
<tr>
<td>Ajax</td>
<td>N/A</td>
</tr>
<tr>
<td>Bold</td>
<td>0/$0.055</td>
</tr>
<tr>
<td>Cheer</td>
<td>0/$0.075</td>
</tr>
<tr>
<td>Era Plus *</td>
<td>0/$0.038</td>
</tr>
<tr>
<td>Fab</td>
<td>0/$0.075</td>
</tr>
<tr>
<td>Generic</td>
<td>0/$0.031</td>
</tr>
<tr>
<td>Parade</td>
<td>N/A</td>
</tr>
<tr>
<td>Purex</td>
<td>N/A</td>
</tr>
<tr>
<td>Tide</td>
<td>0/$0.068</td>
</tr>
<tr>
<td>Trend *</td>
<td>0/$0.036</td>
</tr>
<tr>
<td>Wisk</td>
<td>0/$0.059</td>
</tr>
<tr>
<td>Woolite</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Store A</td>
</tr>
<tr>
<td>---------------------</td>
<td>----------</td>
</tr>
<tr>
<td><strong>Granular Bleaches and Bleach Substitutes</strong></td>
<td></td>
</tr>
<tr>
<td>Arm and Hammer</td>
<td>0/0.031</td>
</tr>
<tr>
<td>Biz</td>
<td>17.6/0.10</td>
</tr>
<tr>
<td>Borateem</td>
<td>N/A</td>
</tr>
<tr>
<td>Clorox 2</td>
<td>0/0.051</td>
</tr>
<tr>
<td>Lysol</td>
<td>10.0/0.094</td>
</tr>
<tr>
<td>20 Mule Team Borax</td>
<td>0/0.031</td>
</tr>
<tr>
<td>Purex</td>
<td>0/0.04</td>
</tr>
<tr>
<td>Snowy</td>
<td>noncommittal/0/0.093</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>(Store B’s Snowy had &quot;This formula contains no phosphates&quot; stamped on the box.)</td>
<td></td>
</tr>
<tr>
<td><strong>Granular Dishwasher Detergent</strong></td>
<td></td>
</tr>
<tr>
<td>Albertson's</td>
<td>8.3/0.034</td>
</tr>
<tr>
<td>All</td>
<td>N/A</td>
</tr>
<tr>
<td>Cascade</td>
<td>8.3/0.057</td>
</tr>
<tr>
<td>Electrosol</td>
<td>N/A</td>
</tr>
<tr>
<td>Electrosol Power Boost</td>
<td>7.1/0.034</td>
</tr>
<tr>
<td>Generic</td>
<td>8.3/0.031</td>
</tr>
<tr>
<td>Parade</td>
<td>N/A</td>
</tr>
<tr>
<td>Sunlight</td>
<td>8.1/0.064</td>
</tr>
<tr>
<td><strong>Liquid Dishwasher Detergent</strong></td>
<td></td>
</tr>
<tr>
<td>Cascade</td>
<td>5.9/0.052</td>
</tr>
<tr>
<td>Palmolive</td>
<td>6.3/0.047</td>
</tr>
<tr>
<td>Sunlight</td>
<td>4.0/0.051</td>
</tr>
</tbody>
</table>
## APPENDIX B

**CAPITAL COST BREAKDOWN FOR BIOCHEMICAL PHOSPHORUS REMOVAL**

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lime Feed Facility *</td>
<td>220,770</td>
</tr>
<tr>
<td>Stripper Tank **</td>
<td>374,140</td>
</tr>
<tr>
<td>Mechanism and Warranty **</td>
<td>245,000</td>
</tr>
<tr>
<td>Lime Mix Tank **</td>
<td>158,355</td>
</tr>
<tr>
<td>Pumps</td>
<td></td>
</tr>
<tr>
<td>Anaerobic RAS</td>
<td></td>
</tr>
<tr>
<td>Stripper Supernatant **</td>
<td>10,350</td>
</tr>
<tr>
<td><strong>Total Capital Investment</strong></td>
<td><strong>1,008,615</strong></td>
</tr>
</tbody>
</table>


** estimated from Heim (1980).
APPENDIX C

SOIL DESCRIPTION OF GRANTSDALE LOAM IN MISSOULA VALLEY
REPRINTED FROM (VERHAY, 1987)

SCS Soil Description, Grantsdale Loam

The Grantsdale series consists of deep, well, drained soils that formed in alluvium. These soils are on terraces in intermountain valleys. Slope is 0 to 2 percent. Elevation is 2,800 to 3,500 feet. The average annual precipitation is 11 to 14 inches. The average annual air temperature is 43 to 45 degrees F., and the frost-free season is 105 to 120 days.

Typically, the surface of this Grantsdale soil is grayish brown loam about 9 inches thick. The subsoil is grayish brown to light gray loam about 23 inches thick. The substratum to a depth of about 60 inches or more is light gray and light brownish gray extremely gravelly loamy sand.

Permeability is moderate to a depth of about 32 inches and rapid below this depth. Available water capacity is about 5 inches. Runoff is slow and the hazard of water erosion is slight.

If soil is used for homesite development, it is limited mainly by rapid permeability, cutbank instability, and dustiness. Effluent from septic tank absorption fields may contaminate ground water of nearby surface water. Alternative onsite disposal systems or offsite disposal
should be considered.

These soils are coarse-silty over sandy or sandy-skeletal, mixed, frigid Calciorithidic Haploxerolls.

Typical pedon of a Grantsdale loam, 0 to 2 percent slopes, in irrigated pasture, 2,450 feet south of the northeast corner of sec. 35, T. 12 N, R. 20 W.:

Ap 0 to 9 inches; grayish brown (10YR 5/2) loam, very dark grayish brown (10YR 3/2) moist; moderate fine granular structure; slightly hard, very friable, nonsticky, and nonplastic; many very fine, fine and medium roots; common fine and medium pores; neutral; clear smooth boundary.

B2 9 to 17 inches; pale brown (10YR 6/3) loam, brown (10YR 5/3) moist; weak fine and moderate subangular blocky structure; slightly hard; very hard, very friable, nonsticky, and nonplastic; common very fine, fine, and medium roots; common fine pores; neutral; gradual smooth boundary.

B3ca 17 to 32 inches; light gray (2.5Y 7/2) loam, grayish brown (2.5Y 5/2) moist; weak medium coarse subangular blocky structure; slightly hard, very friable, nonsticky, and nonplastic; few fine roots; common fine pores; disseminated lime; strongly effervescent; moderately alkaline; clear wavy boundary.

IIIC1ca 32 to 36 inches; light gray (2.5Y 7/2) very gravelly loamy sand, grayish brown (2.5Y 5/2) moist; single grain; loose, nonsticky, and nonplastic; 50 % pebbles and
10% cobbles; thin lime coats on undersides of pebbles; strongly effervescent; moderately alkaline; gradual smooth boundary.

**IIC2** 36 to 60 inches; light brownish gray (10YR 6/2) very gravelly loamy sand, dark grayish brown (10YR 4/2) moist; single grain; loose, nonsticky, and nonplastic; 50% pebbles and 10% cobbles; slightly effervescent; mildly alkaline.

The Ap horizon is loam. The B2 horizon is loam and silt loam. The Ap and B2 horizons are slightly acid or neutral. The B3ca horizon is loam or very fine dandy loam and is mildly alkaline or moderately alkaline. The IIC1ca and IIC2 horizons are loamy sand or sand and are 30 to 40 % pebbles and 5 to 20 % cobbles; they are mildly alkaline to strongly alkaline.