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Algae or alfalfa : which should we grow with Missoula's municipal wastewater treatment plant discharge? : an evaluation of the constructed wetland/land application option for Missoula's future wastewater treatment needs

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Algae or Alfalfa

Which Should We Grow With Missoula's Municipal Wastewater Treatment Plant Discharge?

An Evaluation of the Constructed Wetland/Land Application Option for Missoula's Future Wastewater Treatment Needs

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1.0 Executive Summary

The Clark Fork River in western Montana is suffering from a phenomenon known as "cultural eutrophication". Increased loads of the nutrients nitrogen and phosphorous from wastewater discharges and nonpoint sources accelerate the growth of filamentous and diatom algae in the Clark Fork River. These high nutrient concentrations contribute to nuisance algae levels in much of the Clark Fork River mainstem from its headwaters in Butte to its confluence with the Flathead River. Studies dating back as far as the mid-eighties have documented that algae levels threaten or impair beneficial uses in at least 200 miles of the Clark Fork River (MDHES, 1990). The result is adverse impacts to irrigation, recreational, and aesthetic uses, and adverse impacts to aquatic life caused by habitat alteration and historical exceedences of dissolved oxygen standards.

As required under the federal Clean Water Act, the Montana Department of Environmental Quality formally listed the Clark Fork River as a "water quality limited stream" pursuant to Section 303(d) of the Act. This designation recognizes that the Clark Fork River is failing to meet established water quality standards and support it's designated beneficial uses. More importantly, it mandates that a pollution reduction plan—or Total Maximum Daily Load (TMDL)—be developed to reduce nutrient loads, to eliminate nuisance algae growth, and to restore beneficial use support in the Clark Fork.

In 1994, the Montana Department of Environmental Quality began discussions with a group of basin stakeholders—including City/County governments, regulatory agencies, representatives from the four major nutrient dischargers, and river conservation groups—to develop a nutrient reduction plan for the Clark Fork River.

After four years of negotiations, Montana DEQ and the basin stakeholders adopted the Clark Fork River Voluntary Nutrient Reduction Plan (VNRP) in August, 1998. The VNRP seeks to eliminate algae-related water quality problems in the Clark Fork River by calling to meet the following targets: 1) acceptable algae density levels for the Clark Fork River; 2) instream nitrogen and phosphorous concentrations needed to achieve those algae targets; and 3) estimated nutrient load reductions for various sources needed to meet the instream algae and nutrient targets. The VNRP only requires the targets be achieved during summertime, low flow conditions. It also provides a ten year time frame during which signatories agree to take steps necessary to meet the newly established targets.

Missoula is the largest population center in the Clark Fork basin, and its' Municipal Wastewater Treatment Plant is the largest point source discharger of nutrients to the Clark Fork, accounting for approximately 61% of the soluble N and 55% of the soluble P loads respectively. Consequently, Missoula is now evaluating treatment alternatives to reduce nutrient concentrations in the plant's discharge in order to meet the VNRP targets.

Currently, the City plans to upgrade the existing wastewater treatment plant to a biological nutrient removal (BNR) system. In the BNR system, nitrogen is removed from the waste stream by oxidizing ammonia compounds to nitrate, then reducing the nitrate to nitrogen gas which is eventually released to the atmosphere. Phosphorous is removed in anaerobic zones where certain bacteria take in high quantities of phosphorous.

The City's engineering consultants have developed preliminary design plans for a BNR system capable of producing an effluent with 1 mg/L phosphorous and 10 mg/L nitrogen. They estimate that upgrading the existing treatment plant to a BNR system that can treat 12.6 mgd—the wastewater volume expected twenty years from now—will cost approximately $94 million. This cost estimate includes: 1) $56 million for expanding the sewage collection system; and 2) $37 million in expansions and upgrades at the WWTP (initial upgrade $13 million and another $ 24 million upgrade within the next five years) (personal communication, Dave Clark). In spite of these high costs, the consultants believe that the expansion and upgrade to a BNR system is the most cost effective way for Missoula to meet the VNRP targets while still being able to accommodate expected growth in the valley.

Another option that the City of Missoula has considered in their Facility Planning process is reusing the municipal wastewater discharge for irrigation purposes—a process known as land application. Land application is a widely accepted method of wastewater treatment that recognizes that municipal wastewater discharges can be a valuable resource, not just a wastestream needing expensive treatment. In the land application process, municipal wastewater is delivered to irrigated pastures and applied at a rate consistent with the water and nutrient requirements of the local crops. The nutrients that once grew mats of algae in the river fertilize the irrigated crop instead. And because municipal wastewater flows are consistent, the water is available to irrigators in even the driest summers when surface water diversions may become problematic.

Recent studies have demonstrated that there is a sufficient amount of suitable irrigated land in the Missoula Valley to safely land apply the 7.5 mgd of wastewater the treatment plant currently discharges, as well as the 12.6 mgd flow used in the Facility Planning process (Land&Water, 1995). As such, land application of Missoula's wastewater is a viable option that can meet the newly imposed VNRP nutrient limits.

However, the City's engineering consultants estimate that a land application system capable of treating these projected flows would cost at least $110 million over twenty years. These costs include: 1) $56 million for expanding the sewage collection system; 2) $27 million for purchasing the irrigable land; and 3) another $65 million to construct an effluent distribution system to deliver the treated wastewater to the irrigated pastures (Brown&Caldwell, 1996). In addition to these higher costs, the consultants also point out that a land application system may be difficult to implement due to state and local guidelines governing municipal wastewater reuse.

These guidelines often include setbacks from residential homes, water supply wells, and public right-of-ways/roads, and signage on the irrigated land. They are adopted to assure the wastewater is applied in a safe manner, and that public health is protected from bacteria, viruses, and nutrients that may still be present in the wastewater after secondary treatment and disinfection. Unfortunately, these restrictions are often a disincentive for irrigators who may consider land applying wastewater on their pastures.

Given the higher predicted costs, and potential difficulties posed by land application regulations, the consultants have advised the City against land application in favor of the BNR system. I question these findings and present evidence that Missoula could implement a land application system that will meet Misoula's VNRP obligations for much less cost than the consultants have estimated. To do so, however, the City would need to improve the quality of its' treated effluent so that local irrigation companies would allow it to use the existing irrigation ditch system to distribute the wastewater.

To achieve this goal, and to facilitate seasonal land application of Missoula's wastewater discharge, Missoula should consider building a constructed wetland system to provide tertiary treatment—or "polishing"—of the wastewater before re-using it for irrigation purposes. Constructed wetlands are man-made wetlands designed to mimic the water purifying processes that occur in natural wetlands. Treatment processes that occur in the wetland include denitrification to reduce nitrogen concentrations, adsorption and plant uptake which may reduce phosphorous levels, and settling and filtration for removal of suspended solids.

Under the constructed wetland/land application scenario, the City of Missoula would continue to provide secondary treatment and disinfection at the wastewater treatment plant. Once treated, the wastewater would be delivered to a constructed wetland system where additional "polishing" would occur. From there, the wastewater would be delivered to the existing irrigation ditch system, where it would blend with the relatively cleaner river water already flowing through the ditch system. After mixing, irrigators already using the ditch system would use the water to irrigate their crops, just as they do today.

Using the existing irrigation ditch system to transport the treated wastewater to the land application sites would make the land application option considerably cheaper than originally estimated by: 1) eliminating the need to spend $64 million for an effluent distribution system; and 2) allowing the City to explore cheaper ways—including leases or easement options—to secure access to the land needed to apply the wastewater. As such, land application is in fact a viable, cost-effective way to meet Missoula's VNRP obligations.

Preliminary cost estimates for the constructed wetland/land application option have been developed. Based on discussions with professional engineers in the wastewater treatment field, it is estimated that Missoula could implement this option for approximately $20-$25 million dollars. This cost estimate includes: 1) $10 million to expand the treatment capacity at the WWTP from 9 mgd to 12 mgd; 2) $500,000 for a UV light disinfection system; 3) $750,000 to purchase land for the constructed wetland site; 4) $5-10 million for wetland construction; and 5) $5 million for an effluent distribution system. There may be additional costs associated with implementing this option, including assisting the local irrigation companies with ditch maintenance, and negotiating leases and/or conservation easements to assure access to the irrigated land. Even so, these estimated costs are considerably less than the $37 million needed for expansion and upgrade to a BNR system.

Land applying Missoula's wastewater discharge after polishing in a constructed wetland system is an option Missoula should consider carefully for a number of reasons. First, preliminary cost estimates indicate it can be accomplished for less cost than the BNR upgrade. Second, it will meet nutrient load reductions required under the VNRP because the discharge would be diverted from the river during the irrigation season, which is the same time the VNRP nutrient limits are in effect (June 21 to September 21). And finally, the constructed wetland/land application system will provide a number of ancillary benefits to the Missoula community, including providing an additional source of water and nutrients for local irrigators, preserving open spaces, creating new wetland habitat, and providing unique educational and recreational opportunities for the valley's residents.

The purpose of this paper is to demonstrate that: 1) Missoula's municipal wastewater discharge is a significant contributor to the nuisance algae problem in the middle Clark Fork River; 2) that land application of Missoula's municipal wastewater discharge during the summer months is an option that will achieve the nutrient reduction requirements set forth in the Clark Fork River VNRP; 3) that using a constructed wetland system to polish the wastewater will provide an added level of treatment that makes land application a more attractive option to local irrigators; and 4) that selecting the constructed wetland/land application option will cost less than a BNR upgrade while also providing the Missoula community with a wide range of benefits that go beyond restoring water quality in the Clark Fork River.

2. 0 The Role of Nutrients and Algae in Aquatic Ecosystems

The nutrients nitrogen and phosphorous, and the algae growth they promote, are natural components of all aquatic ecosystems—including rivers, lakes, and estuaries. Algae use the suns' energy to bind carbon, hydrogen, nitrogen, phosphorous, and other elements into living matter, or biomass. This process is known as primary production (Likens, 1972). Macroinvertebrates then transfer energy from the primary producer (algae) to consumers including insects, fish, raptors, and humans. In healthy aquatic ecosystems, the balance forged between producers and consumers supports a diverse assemblage of plants, insects, and animals.

However, if nutrient concentrations and algal productivity increase over time, changes begin to occur in the system. Nutrient and organic matter enrichment can result in increased biological productivity and decreased volume within the waterbody. As time goes on, dense mats of algae may develop. The algae releases oxygen during daylight hours but at night, in the absence of photosynthesis, they deplete the oxygen needed by fish and other aquatic organisms. Seasonally, as the algae die and decay, oxygen demanding sludge deposits are formed, and water clarity and the visual appeal of the river are reduced (Ingman, 1992). This process is called "eutrophication" .

"Eutrophication" is defined as the natural or artificial addition of nutrients to waterbodies, and to the *effects* of the added nutrients (NAS, 1969). Eutrophication occurs in undisturbed lakes, for example, as part of the natural aging process, which eventually terminates with the disappearance of the lake itself. However, when human activities accelerate the rate of eutrpohication, and undesirable impacts occur as a result, the process is known as "cultural eutrophication (Hasler, 1947). It's important to note that when the results of eutrophication are caused by and undesirable to man, the process is often considered a form of pollution, but these two terms are not necessarily synonymous.

3. 0 Studies Documenting Cultural Eutrophication in the Clark Fork River

As far back as the mid-1970's, state regulatory agencies—most notably the Montana Department of Health and Environmental Sciences (MDHES)— have received citizens' complaints about nuisance algae growth in the Clark Fork River. Citizens observed that the Clark Fork below Missoula was coated with "river slime"—or diatom algae—and often times covered in foam. In the upper Clark Fork, water users reported that entire sections of stream channel were sometimes choked with the filamentous algae *Cladophora* during the summer low-flow periods.

Concern over the nuisance algae problem in the middle Clark Fork intensified in 1983 when the Champion International Pulp Mill in Frenchtown (now Stone Container) sought to increase its nutrient discharge to the Clark Fork River. In addition to concerns already raised by Montanans, our neighbors in Idaho worried that increased nutrient loads would affect water quality downstream in Lake Pend Oreille. Regulators and policy makers soon realized this issue demanded special attention.

Over the next five years, researchers embarked on a series of long-term monitoring and assessment programs to learn more about the causes, effects, and potential solutions for the nuisance algae problem in the Clark Fork River. These studies included: 1) the Clark Fork Basin Project; 2) the 525 Study; and 3) periphyton and macroinvertebrate studies.

3.1 Clark Fork Basin Project

In 1985, Governor Ted Schwinden initiated a basin-wide water quality status and trends monitoring program. This monitoring and assessment program sought to bring together fragmented information about the basin, and to develop a management plan for the future. The results of the study were incorporated into the ***Clark Fork Basin Project: Status Report and Action Plan*** (Johnson and Schmidt, 1988).

Researchers and citizens observed that dense mats of filamentous green algae and diatoms were aesthetically unattractive and affected water uses, including recreation and irrigation. Johnson&Schmidt concluded that with the exception of heavy metal pollution, nutrients and algae was a very high priority issue for the future. Unfortunately, the report also noted that despite the concern about the problem, very little was known about the sources or fate of nutrients in the Clark Fork River system.

3.2 The "525 STUDY"

Soon after the release of the Clark Fork Basin Project, Montana's nutrient pollution and algae problem in the Clark Fork River became a national priority. After several requests from the State of Montana, and successful lobbying by members of the Clark Fork Coalition and other citizens, the U.S. Congress passed Section 525 of the Clean Water Act Amendments in 1987. Section 525 directed EPA to conduct a comprehensive study of Lake Pend Oreille, the Clark Fork River, and its tributaries to identify the sources of nutrient pollution in the basin, and to report their findings and recommendations to Congress.

The states of Montana, Idaho, and Washington then embarked on a three year study of the Clark Fork River basin and Lake Pend Oreille from 1988 to 1991. The Montana

Department of Environmental Health and Sciences(MDHES) formulated a monitoring and assessment plan to : 1) determine the extent and magnitude of excessive algae production in the Clark Fork River; 2) identify and measure nutrient sources; and 3) develop nutrient level/biological response criteria for future planning purposes (Ingman, 1992).

From 1988 to 1991, MDHES researchers measured the concentrations of nitrogen and phosphorous at over 50 locations in the Clark Fork basin. Dissolved oxygen levels were also monitored at several locations along the mainstem. Special attention was paid to the soluble, inorganic forms of nitrogen and phosphorous because they are most readily available for use by algae. Additionally, sampling efforts focused on the summertime, low flow period in order to gather data during the time of year the algae-related impacts were the most severe (Ingman, 1992b).

3.2.1 Results of the 525 Study

The 525 Study confirmed what the Clark Fork Basin Project researchers had suspected. That is, high concentrations of phosphorous and nitrogen in the Clark Fork River contribute to nuisance levels of attached algae. Moreover, it documented that nuisance algae threaten or impair beneficial water uses in at least 211 miles of the Clark Fork River and its headwater tributary Silver Bow Creek (MDHES, 1990). Finally, it pinpointed the stretches of the river where the algae problems are most severe, and identified the major nutrient sources. Not surprisingly, the reaches of river downstream of the basin's municipal wastewater treatment plants had the highest concentrations of soluble nitrogen and phosphorous, and supported the highest levels of attached algae.

Nutrient Loading Results

Instream nutrient sampling demonstrated that wastewater discharges contributed the vast majority of the soluble nutrient load to the Clark Fork River during the summertime, accounting for 82 percent of the soluble P and 70 percent of the soluble N loading measured from 1989-1991. The majority of the nutrient load associated with wastewater discharges came from just four sources: the Missoula, Butte, and Deer Lodge municipal wastewater treatment plants, and the Stone Container Corporation kraft mill at Frenchtown (Ingman, 1992).

Of these four point sources, the Missoula Wastewater Treatment Plant was the largest source of nutrients from the wastewater discharges, accounting for 62 percent of soluble nitrogen and 55% of soluble phosphorous load for the entire Clark Fork River (Figure 1). In the middle reaches of the Clark Fork which are the focus of this paper, wastewater discharges accounted for 75% of the nutrients, and of that total, about 97% came from the City of Missoula (Ingman, 1992b).

Algae Density Results

The 525 Study also evaluated instream nutrient concentrations as they related to algal densities in the Clark Fork. In this analysis, researchers observed the highest densities of attached algae in the upper Clark Fork were between Drummond and the Blackfoot River confluence, and in the middle reaches of the Clark Fork between Missoula and Harpers Bridge (Ingman, 1992).

Both reaches were clearly impacted by the high nutrient loads discharged from the wastewater treatment plants mentioned above. Dense mats of filamentous algae above Missoula, and heavy growths of diatom algae below Missoula reduced dissolved oxygen levels in the water column and impaired irrigation and recreation uses of the river (Johnson and Schmidt, 1988). The highest average algal levels in the middle Clark Fork were three times higher than the levels proposed to protect against undesirable changes in the aquatic community, and six times higher than those proposed to protect to recreation and aesthetics (Ingman, 1992b).

3.3 Periphyton and Macroinvertebrate Sampling

In addition to the 525 Study documenting how much algae was in the river, two other long-term studies began in the late eighties to determine exactly how nuisance algae growth affected the biological integrity of the Clark Fork's aquatic ecosystem. These were Erich Weber's Biological Integrity Assessments (Weber, 1995) and Dan McGuire's Macroinvertebrate Community Biointegrity Assessments (McGuire, 1995).

3.3.1 Biological Integrity and Impairment Based Algae Associations

Erich Weber's long-term study of benthic algae composition in the Clark Fork began in 1986. The purpose of the study was to gain a better understanding of the impacts that cultural eutrophication was having on the river's biological health. Biological integrity has been defined several ways by researchers over the years, but generally speaking, it is the ability of an aquatic ecosystem to support and maintain a community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitats within a region (Karr and Dudley, 1981).

Algal composition is one aspect of the biological integrity of aquatic ecosystems. Periphyton is the assemblage of small, often microscopic organisms (macroinvertebrates, bacteria, fungi, and benthic algae) that live attached to or in close association with the surfaces of submerged substrates. Benthic algae typically dominate the periphyton community in most waters, and can be conveniently divided into two major groups: the diatoms and the non-diatoms, by the presence or absence of a rigid, siliceous cell wall (Weber, 1995).

Researchers in Montana have developed a periphyton sampling procedure to expedite Biointegrity assessments. A pollution index was proposed by Bahls (1993) as a shorthand method of summarizing the information contained in the three pollution tolerance groups of Lange-Bertalot (1979). Using those protocols, DHES Water Quality Division personnel collected periphyton samples from natural substrates at 25 monitoring locations on the Clark Fork and selected tributaries. Sampling was collected from August 15 through August 23, 1993, during the low flow regime when nuisance algae problems were the worst (Weber, 1995).

Results

The Clark Fork River periphyton sampling program found that biological integrity in the Clark Fork River was impaired to varying degrees by high concentrations of nitrogen and phosphorous, and by the excessive algae growth those high concentrations of nutrient support. In 1993, the Clark Fork River downstream of the Missoula metropolitan area and the municipal wastewater treatment plant discharge had a lower biological integrity rating than upstream of the city, with a somewhat higher level of aquatic life impairment. This continued gradual downward trend (temporal) in biointegrity that was evident since at least 1990.

Similar results were found in the 1994 and 1995 studies, suggesting that water quality and aquatic life continue to suffer moderate impairment downstream of Missoula's municipal wastewater discharge.

3.3.2 Macroinvertebrate Community Biointegrity Studies

The mid-eighties also marked the time that researchers began assessing the macroinvertebrate community in the Clark Fork to determine what impacts the high nutrient concentrations and algal densities were having on this part of the biological community in the river. These biointegrity studies examined the abundance and diversity of aquatic insects, or macroinvertebrates in the Clark Fork. Macroinvertebrates are considered good indicators of water quality and are commonly used to evaluate environmental impacts to streams. Healthy streams support diverse assemblages that include mayflies(Ephemoptera), stoneflies(Plecoptera), caddisflies(Trichoptera), true flies(Diptera), beetles(Coleoptera) and many others (McGuire, 1996).

Macroinvertebrates provide energy pathways from primary producers(algae) and organic materials to consumers(humans, fish, etc.). As integral components of stream ecosystems, macroinvertebrate assemblages reflect the cumulative impacts of all pollutants, including toxins, nutrients, and sediment (McGuire, 1996).

The Montana Department of Environmental Quality (DEQ, formally DHES) has conducted annual macroinvertebrate surveys in the Clark Fork River Basin since 1986. The analysis was specifically designed to evaluate environmental conditions in the Clark Fork River Basin and builds on the concepts and techniques used in the U.S. EPA Rapid Bioassessment Protocols (Plafkin et al., 1989).

The analysis integrates ten measures of macroinvertebrate structure and function into a single index of biological integrity. Each metric measured a different aspect of community composition, structure, or function. With nine years of data for most monitoring sites, a detailed picture of environmental health and water quality trends in the Clark Fork Basin has been developed (McGuire, 1996)

Results

McGuire's biointegrity assessments found a consistent pattern of impairment during all nine years of monitoring. Downstream from Missoula, the Clark Fork River was slightly impaired in most years. Increased nutrient was evident from the confluence of the Bitterroot River to Huson. Impacts in this reach were attributed to nutrients from the Missoula WWTP, the Bitterroot River, and the Stone Container Kraft mill (McGuire, 1996)

Similar impacts were observed in 1995. Again, the Clark Fork at Harpers Bridge site had the lowest mean biointegrity (74%) among stations from Missoula to the Flathead River. Biointegrity was slightly impaired (82%) in 1995. Nutrient/organic pollution has been indicated at Harpers Bridge throughout the 10-year monitoring period. Impacts have generally been slight, although moderate impacts were indicated in 1988 and 1993. Impacts appear to result from assimilation of nutrients from the Missoula WWTP and the Bitterroot River (McGuire, 1997).

3.4 Conclusion

The 525 Study's long-term water quality and biointegrity assessments have provided conclusive evidence high nutrient concentrations promote nuisance algae levels that result in adverse impacts to aquatic life and water uses in the Clark Fork River. More specifically, they have documented that the Missoula Wastewater Treatment Plant is a significant source of nitrogen and phosphorous in the middle Clark Fork, and that biological integrity in the reaches downstream of the plant is impaired to varying degrees by excessive algae growth.

Given these findings, drafters of the 525 Study recommended that Montana develop a comprehensive program to control nutrient sources—including the Missoula Wastewater Treatment Plant— in the Clark Fork Basin. Such a program would have many benefits, including: 1) decreasing maximum densities of attached algae; 2) reducing the impacts that excess algae growth has on recreation, aesthetic, aquatic life, and irrigation uses: 3) reducing respiration by the river's benthic community, leaving more dissolved oxygen in the river for trout and aquatic invertebrates; and 4) eliminating violations of state water quality standards for dissolved oxygen (Ingman, 1992b).

4.0 Regulatory Process TMDL/VNRP

The 525 Study recommendations are in keeping with the federal Clean Water Act which requires development of a pollution reduction strategy for impaired waterbodies like the Clark Fork River. Section 303(d) of the federal Clean Water Act mandates that the states and EPA identify water quality-limited streams (like the Clark Fork), and determine the Total Maximum Daily Load (TMDL) of pollutants for those waterbodies. The TMDL is the amount of a given pollutant a waterbody can assimilate without causing adverse impacts. That load is then divided among the various point and nonpoint sources to the waterbody. Dividing the load is called a Waste Load Allocation for point sources and Load Allocation for nonpoint sources. A TMDL plan must also include a Margin of Safety to address potential uncertainties in the analysis.

The 525 Study's comprehensive water quality assessments have documented that the Clark Fork River is a water quality-limited stream, as evidenced by nuisance algae growth that threatens and/or impairs beneficial uses, including irrigation, recreation, and aesthetics. Consequently, the Montana Department of Health and Environmental Sciences formally listed the Clark Fork River as a water quality-limited stream in 1992. Additionally, DHES designated the Clark Fork as a "high priority" for TMDL development in recognition of the high level of public concern over the nuisance algae problem.

In 1994, Montana DEQ began working with the Tri-State Implementation Council's Nutrient Target Subcommittee— a stakeholders group created in response to the 525 Study—to determine the best strategy for implementing a TMDL in the Clark Fork basin (TSIC, 1998). Over the next four years, the Subcommittee reviewed available data on the Clark Fork and other river systems to determine: 1) an "acceptable" algae density for the river; 2) the instream nitrogen and phosphorous concentrations needed to achieve those algal densities; and 3) the estimated nutrient load reductions needed to achieve these instream algae and nutrient targets. They also spent a considerable amount of time deciding what regulatory approach would be used to assure the necessary steps are taken to meet the targets.

After four years of deliberation, negotiation, and debate, the Nutrient Target Subcommittee submitted the Clark Fork River Voluntary Nutrient Reduction Plan (VNRP) to EPA for consideration as a "functional equivalent" of a TMDL. The VNRP represents the comprehensive nutrient control strategy recommended in the 525 Study, and sets forth the following goals to reduce nuisance algae growth and restore water quality in the Clark Fork River: 1) a summer average algae density of 100 mg/m^2 (150 max.) 2) instream nutrient targets of 300 micrograms per liter N and 20 micrograms per liter P above Missoula and 39 ug/L P below Missoula, and 3) estimated nutrient load reductions for both point and nonpoint sources of nutrients needed to achieve the targets at summertime, low flow conditions.

Algae Density Target

The primary goal of the VNRP is to reduce attached algae densities in the Clark Fork to "acceptable" levels. To establish this level, the Subcommittee reviewed studies completed by Smith and Dodds (1995) and Watson and Gestring (1996). Smith and Dodds (1995) defined nuisance algae levels as those higher than 100 mg/m^2, based on their own review of over 200 river systems, and on previous findings reported by Horner et al. (1983) and Welch et al. (1988). Additionally, Watson and Gestring recommended that algae densities greater than 100 mg/m^2 be considered unacceptable unless it could be shown that higher levels are natural and not problematic for a particular site.

Based on these recommendations, and their own professional judgement, the Subcommittee selected 100 mg/m^2 (mean) and 150 mg/m^2 (maximum) as the algal density targets for the Clark Fork River VNRP.

Instream Nutrient Targets

After establishing the algal density target, the Subcommittee proposed instream nutrient concentrations needed to achieve the algae targets. In doing so, the Subcommittee recognized that adverse impacts due to nuisance algae growth typically occur during the summertime when low stream flows and higher water temperature combine to exacerbate alage-related water quality problems. Based on that fact, they agreed that the nutrient targets would only apply from June 21 – September 21.

The first estimates for instream nutrient targets were developed during the 525 Study. Watson (1990) conducted a series of artificial stream studies to determine how attached algae responded to various concentrations of nitrogen and phosphorous in the water column. This study found that as soluble nutrient concentrations were reduced below 30 micrograms per liter P and 250 micrograms per liter N—the "saturation" concentrations—that a corresponding reduction in algae levels occurred.

Ultimately, Watson recommended 6 micrograms per liter P and 30 micrograms per liter N as the proposed summer instream nutrient target concentrations because concentrations have to be well below saturation levels to illicit instream algae reductions. Ingman concurred with the recommended targets because they were similar to the concentrations observed in reaches of the river that did not support nuisance algae growth.

Several members of the Subcommittee were concerned that these proposed nutrient targets would be extremely difficult and expensive to achieve. Consequently, they hired Val Smith and Walter Dodds to conduct an independent, third party review of the proposed nutrient targets. Smith and Dodds (1995) reviewed a database of over 200 rivers to compare algae densities with instream nutrient concentrations. One of their significant conclusions was that instream dissolved nutrient concentrations related poorly to algae density. Consequently, they recommended the Subcommittee set nutrient targets based upon the total nitrogen and phosphorous concentrations, rather than the soluble fraction recommended by Watson. They concluded that maintenance of instream nutrient concentrations of less than 350 micrograms per liter total N and 45.5 micrograms per liter total P would prevent nuisance algae densities of greater than 100 mg/m2.

The Subcommittee then used the information developed by Watson, Smith, and Dodds to develop the final target nutrient concentrations for the Clark Fork River VNRP. The Subcommittee decided to take a conservative approach and adopted the following instream nutrient targets: 300 micrograms per liter total N in the Clark Fork from Butte to the Flathead River confluence; 20 micrograms per liter total P in the upper river where *Cladaphora* algae was a problem; and the 39 micrograms per liter total P in the Clark Fork downstream of the Reserve Street bridge in Missoula, where diatom algae was the primary problem. This distinction is important for Missoula because it meant that the phosphorous limit will be less stringent than the one applied upstream.

Estimated Nutrient Load Reductions

The final component of the VNRP nutrient control strategy was to estimate the nutrient load reductions needed by the various point and nonpoint source discharges in order to meet these newly established instream nutrient targets. Because adverse impacts usually occurred during summertime, low flow conditions, the Subcommittee based the projected load reductions on what level of reduction would be needed to meet the instream nutrient targets during extreme low flow conditions—defined as the 30-Q-10.

The Subcommittee used a model developed by Science Applications International Corporation (SAIC), and modified by DEQ and EPA, to predict the level of nutrient load reduction needed to meet the targets during the summertime low flow conditions. Preliminary estimates produced by the model found that the City of Missoula would have to reduce their soluble nutrient load by over 90% in order to meet the nutrient targets.

Representatives from Missoula believed these target load reductions would be difficult to achieve under the City's current wastewater flow regime, and next to impossible to meet as growth continued in the future. Members of the Subcommittee also questioned the reliability of the SAIC model, and its ability to accurately predict algal response to nutrient load reductions. Given these uncertainties, the Subcommittee agreed to allow Missoula to move forward with their plans to upgrade their wastewater treatment, and to use a feedback loop of monitoring and assessment to determine if additional reductions were needed.

5.0 Treatment Alternatives for Missoula

As the largest population center in the basin, the City of Missoula is also the largest point source of nutrients to the river. Instream water quality monitoring clearly demonstrates the Missoula Wastewater treatment plant causes elevated concentrations of nitrogen and phosphorous in the Clark Fork River downstream of the discharge. Additionally, periphyton and macroinvertebrate sampling show that these elevated nutrient concentrations cause nuisance algae growth that impairs beneficial use support. Consequently, the City is now evaluating options to reduce their nutrient load to the river in order to achieve the newly imposed VNRP nutrient targets.

To evaluate these options, Missoula contracted with Brown & Caldwell—an engineering consulting firm—to conduct their 201 Facilities Plan. The goal of the 201 planning process is to identify the most efficient and cost effective ways to collect, treat, and dispose of Missoula's municipal wastewater discharge. An important objective in the 201 Facility Plan is to protect Missoula's sole source aquifer and to restore water quality in the Clark Fork River while accommodating population growth expected in the future. As such, the contractors have focused much of their effort on evaluating wastewater treatment options that will meet the newly adopted VNRP nutrient targets, both now and in the future.

From 1995 to 1997, Brown&Caldwell have evaluated three treatment options: advanced treatment (biological nutrient removal), land application of treated water, and constructed wetlands treatment. Based upon their analysis of technical, economic, and practical considerations, Brown & Caldwell have recommended upgrading the existing wastewater treatment plant to a biological nutrient removal (BNR) system to reduce average nutrient concentrations in the effluent from 3 mg/L P and 20 mg/L N to 1 mg/L P and 10 mg/L N.

5. 1 The Biological Nutrient Removal Option

Biological nutrient removal systems are a proven technology for wastewater treatment. In the BNR system, nitrogen is removed from the waste stream by oxidizing ammonia compounds to nitrate, then reducing the nitrate to nitrogen gas which is eventually released to the atmosphere. Phosphorous is removed in anaerobic zones where certain bacteria consume large quantities of phosphorous. Importantly, the biological processes that drive the system are effective under a wide range of climatic conditions, including those seen here in western Montana.

The City of Kalispell, MT recently upgraded their municipal wastewater treatment plant to a BNR system in 1992 . The facility has been very successful at meeting treatment objectives over the past six years, achieving phosphorous concentrations well below the 1 mg/L limit, and removing upwards of 80% of the influent nitrogen load. In fact, the plant operators recently earned honors as the best run municipal wastewater treatment plant in EPA Region VIII. These experiences at Kalispell, and a number of other systems in the

U.S. demonstrate that BNR treatment system is a viable alternative for Missoula's wastewater treatment needs.

Based on this and other factors, the City's engineering consultants recommended that Missoula build a similar facility to meet current and future wastewater treatment needs, including the VNRP nutrient targets. They believe it's the best option for Missoula for a number of reasons, including: 1) the performance of BNR systems is controllable and predictable; 2) plant operations can be modified to improve performance; 3) weather impacts on operation are minimized, and 4) does not require the substantial investments in land purchases that are required for land treatment alternatives (Brown&Caldwell, 1996).

Aside from these operational advantages, the consultant's feasibility analysis also found that an upgrade to a BNR system is the most cost-effective way for Missoula to meet their wastewater treatment needs. Preliminary design specifications were developed based on sizing requirements for a BNR facility capable of treating 12.6 million gallons of water per day (mgd)—the estimated wastewater inflow to the plant in twenty years—and producing an effluent quality of 1 mgP/L and 10 mgN/L. Initial cost estimates show it will cost approximately $94 million to provide BNR treatment for Missoula's future wastewater needs (Figure 2). This estimate includes: 1) $56 million for expansions of the sewage collection system; 2) and $38 million for expansions and upgrades at the existing WWTP (initial $14 million upgrade, and another $24 million expansions an upgrade within the next five years) (personal communication, Dave Clark).

In spite of Brown&Caldwell's positive evaluation of a BNR system, there are concerns associated with this proposal. First, the upgrade to BNR is very capital intensive, and existing rate payers will have to pay a large share of the costs for upgrades needed to accommodate future growth in the valley. Second, the Operation and Maintenance (O&M) costs for a BNR treatment system are very high. Brown&Calwell's cost estimates indicate that long-term O&M costs could be over $1 million per year.

Finally, there are still questions as to whether the proposed upgrade will meet the instream nutrient targets in the VNRP. The "agency model" predicted that Missoula would need to produce an effluent with .75 mg/L phosphorous and 9 mg/L nitrogen in order to meet instream targets during low flow conditions. As discussed above, the BNR system proposed by Brown&Caldwell will be designed to produce effluent concentrations of 1 mgP/L and 10 mgN/L. While there are questions regarding the accuracy of the agency model, Missoula must still consider the fact that additional upgrades to the BNR system—such as effluent filtration—may be needed to meet the VNRP nutrient targets.

In spite of these concerns, City officials and engineers appear ready to move forward with the BNR option. A recent article in a local newspaper, Mayor Mike Kadas and Director of Public Works Bruce Bender both indicated they support the BNR proposal. As Mr. Bender put it "the door is open and we're pretty much committed to walking down the hall" (*Missoula Independent*, 1998).

5.2 The Land Application Option

Another option Brown&Caldwell evaluated in the 201 Facilities planning process is land application of Missoula's municipal wastewater discharge. Land application is a widely accepted method of wastewater treatment that recognizes that municipal wastewater discharges can be a valuable water resource, not just a wastestream needing expensive treatment.

In the land application process, treated municipal wastewater is delivered to irrigated pastures and applied at a rate consistent with the water and nutrient requirements of the selected crop. The nutrients that once grew mats of algae in the river fertilize the irrigated crop instead. And because municipal wastewater flows are consistent, the water is available to the irrigators in even the driest summers when surface water diversions may become problematic.

Land application of municipal wastewater has become increasingly popular in the western United States—including Montana— as the demand for limited water resources increases, and as the restrictions on discharging wastewater to sensitive surface water streams increases. Land application is a particularly attractive option for Missoula to consider because the VNRP nutrient targets apply during the summer months, the same time as the irrigation season.

In fact, drafters of the 525 Study specifically recommended land application as an option for municipal wastewater treatment plants to consider. They estimated that if the entire volume of municipal wastewater from Deer Lodge and Missoula were utilized for irrigation purposes during the months of July through September, summer nutrient loading to the upper and middle reaches of the Clark Fork could decrease by as much as 30% to 70%, respectively. Additionally, nutrient concentrations in the reaches below these municipal wastewater discharges would decline by as much as 70% as well (Ingman, 1992b).

The City of Deer Lodge is already moving forward with plans to land apply their wastewater discharge, and Missoula should carefully evaluate the feasibility of doing the same. When doing so, consideration must be given to the following municipal wastewater reuse guidelines and regulations.

5.2.1 Land Application Guidelines

EPA Process Design Manual - Land Treatment of Municipal Wastewater

The United States Environmental Protection Agency (EPA) first adopted guidelines for land application of treated municipal wastewater in their 1981 Process Design Manual. In that manual, land treatment is defined as the controlled application of wastewater onto the land surface to achieve a designed degree of treatment through natural physical, chemical, and biological processes within the plant-soil-water matrix. Slow rate land treatment is defined as the application of wastewater to a vegetated land surface with the applied wastewater being treated as it flows through the plant soil matrix (USEPA, 1981).

In addition to providing these basic definitions, the manual also provided an explanation of 1) the water treatment mechanisms that occur in the land application process, and 2) guidelines for selecting potential land application sites.

1. Water Treatment Mechanisms

In a land application system, nitrogen is removed from the wastewater by a number of processes including crop uptake, denitrification, ammonia volatilization, immobilization by microbes, and storage in the soil (USEPA, 1981). A thorough understanding of these processes is necessary when municipal wastewater is land applied because nitrogen is usually the pollutant of most concern where protection of ground water quality is a concern. In fact, the manual specifically recommends that land application systems be designed to assure that nitrate nitrogen concentrations in the receiving ground water not exceed 10 mg/L at the project boundary.

Phosphorous is removed from the land applied wastewater by plant uptake and fixation processes in the soil, including adsorption, immobilization, and chemical precipitation. Removal efficiencies are dependent on the soil properties and crops selected, as well as the actual concentration of phosphorous in the wastewater (USEPA, 1981).

2. Site Selection Guidelines

The EPA Manual also provided a number of guidelines for evaluating potential land application sites. Important factors to consider include: 1) soil permeability; 2) slope; 3) climatic conditions; 4) hydraulic loading rates; 5) potential for groundwater pollution; and 6) existing and future land uses.

The manual notes that soil permeability, soil structure, hydraulic conductivity, and slope are all critical factors in site evaluation because they dictate the amount of water that can be applied without overland flow or excessive leaching. Sites with low soil permeability and hydraulic conductivity have a limited capacity to transmit water, while potential impacts to groundwater are a concern at sites with especially high soil permeabilities and hydraulic conductivities. The manual specifically recommends loamy or medium textured soils as the most appropriate for land application sites.

3. Hydraulic Loading Rates

Once the soil properties are characterized, planners must determine the hydraulic loading rate, which is the amount of wastewater that can be applied to a given site per unit area and per unit time. Acceptable hydraulic loading rates can be estimated by using the following water balance equation:

Precipitation + Applied Wastewater = Evapotranspiration + Percolation

Determining the design hydraulic loading rate is critical in the land application design because it is used to estimate how much land is required for the system. Crop selection is also important because preapplication treatment, hydraulic and nitrogen loading rates, and storage depend to some extent on the crop (USEPA, 1981).

4. Other Considerations

The EPA manual also recommends consideration of a number of other important issues associated with land application systems, including capital costs, operation and maintenance costs, public acceptability, ease of implementation, water rights, and treatment consistency and reliability. Experiences at existing land application systems have shown that land leasing has been cost-effective for several hundred projects nationwide (USEPA, 1981).

DEQ Circular WQB-2

The Montana Department of Environmental Quality used the guidelines presented in the EPA manual to adopt regulations and guidelines for irrigation with treated municipal wastewater. These guidelines are found in Circular WQB-2, Appendix B (MDHES, 1995). The purpose of these regulations is to assure that public health is protected when treated municipal wastewater is land applied for irrigation purposes. These regulations recognize that the end use of the wastewater shall dictate the level of treatment needed prior to land application.

For instance, the WQB-2 regulations require varying degrees of disinfection to reduce the amount of fecal colifom bacteria present in the wastewater depending on what types of lands will be irrigated— food crops; fodder, fiber, and seed crops; or landscape irrigation. Circular WQB-2 also requires that an engineering design report be completed to justify the hydraulic and nitrogen loading rates on the irrigated land. Lastly, it requires fencing and buffer zones between the land application sites and residential property if the wastewater is not disinfected prior to reuse.

Missoula Reclamation and Reuse Requirements

Missoula has also adopted local regulations that govern land application and wastewater reuse in the Missoula Valley (MCCHD, 1997). In 1997, the City/County Health Department amended the local Health Code to include these regulations because land application is becoming an increasingly attractive method of wastewater disposal, but must be regulated to protect public health and safety and surface and groundwater quality in the area surrounding the land application sites. Experiences with a poorly designed and operated system at the El Mar Estates provided the incentive for adopting these local regulations.

Missoula City/County regulations are very similar to those adopted by the state of Montana. They require a suitable engineering design report, signing, fencing and buffer strips around the irrigated land, and contingency plans in the event that the wastewater cannot be applied to the designated lands. Missoula's regulations differ slightly from the WQB-2 regulations in that they classify different types of reclaimed wastewater depending on the level of pretreatment and the final quality of the water to be land applied.

For instance, *Class A reclaimed water* must be oxidized, coagulated, filtered, and disinfected with a mean total fecal colifom levels of less than 2.2 fecal colonies per 100 milliliters, while *Class D reclaimed water* only needs to be oxidized and disinfected, and has less than 240 fecal colonies per 100 milliliters. Figure 3 from the County regulations displays the various types of wastewater reuse, and the classes of reclaimed water suitable for those applications.

As with most land application regulations, guidelines in Montana recognize that nitrogen loading rates and the presence of fecal coliform bacteria are the two key factors that may limit the ability to safely apply treated municipal wastewater. In the discussion that follows, it is assumed that any land application system selected by the City of Missoula as a strategy for nutrient load reductions must comply with these local, state, federal guidelines.

5.2.2 Land Application Feasibility Studies

The City of Missoula has expressed interest in the land application option for their wastewater treatment needs since the early 1990's. They have contracted a number of engineering consultants to look in to the cost and feasibility of land application here in the Missoula valley. The finding of these investigations have been presented in at least three different engineering reports: 1) Preliminary Assessment of Land Application (T.D&H, 1991); Preliminary Information on Potential Wastewater Application Sites (Land&Water Consulting, 1995); and 3) Brown&Caldwell's Draft 201 Facility Plan. All three of these reports contain vital information on regulatory, economic, and practical aspects of land application option in Missoula.

The Thomas, Dean & Hoskins Report

In 1990, the City of Missoula hired Thomas, Dean, & Hoskins (TD&H) to evaluate land application of Missoula's municipal wastewater discharge as an option to reduce nutrient loading to the Clark Fork River. Their analysis looked at three types of land application systems: 1) wetlands; 2) land application (irrigation); and 3) rapid infiltration. TD&H contracted Dr. Bill Inskeep— a soils scientist at Montana State University—to determine the basic design components of a land application system for Missoula.

Dr. Inskeep's analysis provided the first comprehensive evaluation of three critical issues that must be considered in the land application option: 1) identification of suitable soil types; 2) the estimated hydraulic loading rates for local crops; and 3) and acceptable nitrogen and phosphorous loading rates.

1. Soils Analysis

In the soils analysis, Dr. Inskeep reviewed Natural Resource Conservation Service (NRCS) Soil Mapping information to identify the various soil types present in the Missoula Valley. This review identified a number of different soil types in the valley, including De Smet loam, Grass Valley silty clay loam, Grantsdale Loam, Moiese Gravelly Loam, Orthents, Aquic Haploxerolls, and Aquolls and Aquepts. After the soil types were identified, a number of soil characteristics were analyzed to determine their suitability for land application sites. Characteristics considered included soil available water holding capacity, permeability, slope, depth to groundwater, erodibility.

Based on this analysis, Dr. Inskeep recommended the following soil types for potential land application sites: 1) the DeSmet Loam series, which are characterized as deep, well-drained soils with high water holding capacity, good permeability, and low soil erodibility; 2) the Grass Valley silty clay loam series, which are also characterized as deep, well-drained soils, but with a lower permeabilities due to the relatively higher clay content; 3) the Grantsdale loam series, which are characterized as deep (although not as deep as the DeSmet series), well drained soils with good water holding capacity and excellent permeability; and 4) the Moiese gravelly loam series, which are characterized as deep, well-drained soils with moderate water holding capacity, moderate slopes, and high permeability.

Importantly, Dr. Inskeep's analysis also found that there is an abundance of these "suitable" soil types in the Missoula valley. For instance, there are over 3,000 acres of the DeSmet Loam, the Grass Valley silt clay loam, and the Grantsdale loam series in the valley, with much of that acreage in relatively close proximity to the wastewater treatment plant.

2. Hydraulic Loading Rates

Dr. Inskeep also conducted a review of the consumptive water use requirements for a number of crops currently irrigated in the Missoula Valley. These crops included alfalfa, grass hay, and spring grain. Consumptive water use requirements were determined by comparing local climatic conditions (including precipitation and evapotranspiration rates) to the amount of water needed for optimum crop yields. The results of this comparison are presented in Figure 4 (TD&H, 1991).

Based on these findings, Dr. Inskeep recommended minimum and maximum irrigation application rates and maximum irrigation application rates for the crops evaluated. He recommended a minimum of 15-17 inches and a maximum of 28 inches of irrigation water per year for the alfalfa and grass hay crops. Moreover, he estimated that at an annual application rate of 28-30 inches per year, approximately 1,420 acres of land would be required to land apply 9 million gallons of water a day—the design flow capacity for the Missoula wastewater treatment plant.

3. Nutrient Loading Analysis

A final component of Dr. Inskeep's analysis was to estimate how much nitrogen and phosphorous these different crops would remove from wastewater used for irrigation purposes. The nutrient concentrations for Missoula's effluent used in Inskeep's analysis were 4.2 mg/L total phosphorous and 34 mg/L total nitrogen. Special consideration was given to the fact that the various crops probably would not use all of the nutrients available in the wastewater.

Inskeep estimated that alfalfa crops could utilize as much as 240-360 pounds of nitrogen per acre per year and 24-36 pounds of phosphorous per acre per year. Grass hay crops were predicted to use between 100-150 pounds of nitrogen and 20-30 pounds per acre of phosphorous per acre per year. However, he noted that nitrogen application rates in excess of 200 pounds per acre per year could be detrimental to alfalfa crops causing reduced yields and decreased inoculation efficiencies.

Based on these review, Inskeep found that even at maximum water application rates of 28 inches per year, the resulting nutrient load to the crops would be approximately 216 pounds of nitrogen per acre per year, and 26 pounds of phosphorous per acre per year—loading rates that grass hay and alfalfa crops should be capable of removing and using productively. Moreover, he found that there is ample suitable irrigation lands in the Missoula Valley to safely land apply 9 million gallons a day of wastewater—the current design capacity of the Missoula wastewater treatment plant.

The Land&Water Report

As part of the 201 Facility Planning Process, Brown&Caldwell contracted Land&Water Consulting to evaluate specific properties in the Missoula Valley for suitability as land application sites. Land&Water reviewed the requirements of Circular WQB-2, the findings of the TD&H Study, and local information on land ownership and use to provide an initial site screening for land application sites. Factors considered in the analysis included available acreage, soil types, distance from the wastewater treatment plant, costs, and potential groundwater impacts.

Land&Water evaluated a total of fourteen properties in the Missoula Valley covering over 10,000 acres of land. After consideration the factors mentioned above an initial ranking of the top six most suitable sites was completed. The top three properties were identified as the Lucier property, the "WWTP floodplain" sites, and the "Airport" property.

The Lucier property encompasses approximately 2,480 acres of land used mostly for irrigated hay and pasture crops. The property is located approximately 7-10 miles northwest of Missoula and is primarily served by the Grass Valley Irrigation District. This property was ranked high due to existing irrigation uses, and due to it's proximity to the Stone Container Pulp Mill which reduces its desirability for future development.

The "WWTP floodplain" property encompasses approximately 800 acres of land located immediately west of the wastewater treatment plant. It ranked highly because of its proximity to the wastewater treatment plant, limited development potential due to floodplain restrictions, and historical agricultural uses. Major constraints with the site include the fact that groundwater is generally shallow (< 20 feet) and regulatory concerns over potential flooding impacts.

The "Airport" property encompasses approximately 1,880 acres of land located within 1.5 to 4 miles from the wastewater treatment plant. Agriculture was the historic land use, with much of the property served by the Hellgate (Flynn/Lowney) Irrigation District. Soils in the area are well suited for land application and potential impacts to groundwater quality are considered low. The major constraint associated with this property is that it is considered prime development real estate, with many of the historically irrigated acres now subdivided.

The results of the Land&Water evaluation clearly demonstrated that there is sufficient suitable agricultural lands in the Missoula Valley to land apply our current and future municipal wastewater discharge. Importantly, many of these properties are already served by existing irrigation ditches, and already use sprinkler irrigation systems, a potential benefit for the land application option. However, the analysis also noted that lands close to the WWTP are under increased development pressure, while lands further away may be cost-prohibitive from the standpoint of delivering the treated wastewater to the irrigated pasture.

The Brown&Caldwell 201 Analysis

Brown & Caldwell incorporated the findings from the TD&H and Land &Water Consulting reports into their evaluation of land application presented in the Draft 201 Facilities Plan. Specifically, they incorporated the hydraulic loading rates and land requirements developed by Inskeep, and the land application site screening analysis conducted by Land&Water Consulting, to develop a cost and feasibility analysis for Missoula to consider. Special consideration was given to the regulatory requirements a land application system would have to meet, including the wastewater reuse regulations and VNRP nutrient targets discussed above.

The Brown&Caldwell analysis identified several constraints with implementing the land application option in Missoula, including: 1) variable water needs by local irrigators, 2) high land use requirements; 3) regulatory requirements: and 4) costs of implementation.

Variable Water Needs

Brown&Caldwell noted that in the land application scenario. Missoula would need to continuously divert wastewater as it exits the treatment plant. Unfortunately, prospective irrigators may not want or need the effluent at all times during the summer, particularly in preparation for and during harvest. Therefore, to make land application a viable option, Brown&Caldwell suggested Missoula may need to construct effluent storage facilities to avoid discharge to the Clark Fork during the summer months when the VNRP nutrient targets are in effect.

High Land Use Requirements

Brown&Caldwell also determined that Missoula would need more land than the 1,420 acres suggested by Inskeep to safely apply the wastewater discharge. They questioned Inskeep's suggestion that 28 inches of water per year could be safely applied, noting concerns over the potential for excess nitrogen loading in the groundwater beneath the land application areas. To address this concern, they recommended using a more conservative hydraulic loading rate of 20 inches per year. This change resulted in increased land requirement for the land application, with estimates of 1990 acres for the 9 mgd design flow, and 2,800 acres for the 12.6 mgd expected in the year 2015.

Regulatory Requirements

Brown&Caldwell also noted that City/County regulations require a permit to land apply water, and that permit applications must include an engineering report explaining how the system will meet Health Department and WQB-2 requirements, including storage, treatment, disinfection, and set backs from the spray area. Additionally, they noted Circular WQB-2 (Section B.8) requires that when the spray field is not owned by the irrigator, in this case the wastewater utility, then a twenty year lease or similar assurance must be negotiated to ensure control of irrigated land.

Cost Concerns

Aside from these operational constraints, Brown&Caldwell concluded that cost was also a limiting factor in the land application option. They estimated that it would cost approximately $110 million to implement the land application option over the next twenty years. Capitalization of storage facilities, piping and pumping distribution systems, and land acquisition were identified as the primary costs associated with establishment of a land treatment system. Land application facilities—i.e. pipes, pumps, and sprinklers—were estimated to cost about $65 million. and acquisition of the land application sites (over 2,800 acres) was estimated to cost another $27 million.

In the end, Brown&Caldwell concluded that upgrading and expanding the existing wastewater treatment plant to a BNR system is a more cost-effective way for Missoula to meet their future wastewater treatment needs. While they recognize that land application is attractive because it diverts nearly all of the nutrient load from the river during the summer months, they recommended BNR because of its favorable cost comparison.

6.0 The Constructed Wetland/Land Application Option

The preceding discussion shows that Brown&Caldwell recommended an upgrade to a BNR treatment system primarily because its' $94 million cost was less than the estimated $110 needed for the land application option. Before Missoula moves forward with implementing a BNR system, however, decision-makers should consider the fact that the land application cost estimates presented by Brown&Caldwell are based on some questionable assumptions. It assumes that Missoula would have to spend $65 million for a wastewater distribution system, and it assumes Missoula would have to spend another $26 million to buy the land to apply the wastewater on.

These assumptions are not necessarily valid. Missoula does not *have* to build an elaborate wastewater distribution system or purchase thousands of acres of land to make the land application option work. The fact is, there are two existing irrigation systems that Missoula could utilize to make the land application option far less expensive than originally estimated. They are the Flynn/Lowney (Hellgate) irrigation ditch and the Grass Valley Ditch.

The Flynn/Lowney ditch transports over 40 cfs of water to some 2,000 acres of irrigated lands in close proximity to the Missoula WWTP. Alfalfa is the primary crop grown, and hand set and wheel line sprinklers are used to apply the water. The Grass Valley irrigation ditch delivers about 100 cfs of water to over 3,000 acres of irrigated pastures in the western half of the Missoula valley (see Figure 5). As with the Flynn/Lowney, nearly all the land on the Grass Valley is spray irrigated with hand set and wheel lines.

Before Missoula rejects the land application option for cost reasons, they should carefully evaluate the potential for using these existing irrigation ditch and sprinkler systems to deliver treated municipal wastewater to land application sites. One way to achieve this would be to simply deliver the wastewater to the Flynn/Lowney ditch which is located immediately adjacent to the Missoula WWTP. In fact, the TD&H Report previously cited identified this alternative as the most cost effective land application option for Missoula to pursue.

However, the TD&H report also noted that the irrigation companies may not want to accept the wastewater due to the regulatory constraints discussed above, and the fact the nutrient rich wastewater may increase aquatic plant growth in the ditches, an issue that is already a problem on the two ditches. One way to address these concerns, and to facilitate use of existing irrigation systems for land application of Missoula's municipal wastewater, is to use a small constructed wetland system to "polish" the wastewater prior to discharge to the ditch.

Constructed wetland technology is widely recognized as a cost-effective, low maintenance option for secondary and tertiary wastewater treatment. A recent article in *Environmental Science and Technology* reported that there are now over 600 constructed wetlands in North America, and another 500 systems in Europe. Constructed wetland systems are attractive because in addition to providing advanced treatment of municipal wastewater, they can also provide additional benefits including increased wildlife habitat and preservation of open spaces. The technology has proven to be effective in a wide range of climates from the warm, moist climates of the southeast U.S. to the arctic cold of Ontario, B.C. It should be considered as a way to polish Missoula's municipal wastewater in order to reduce concerns about using the wastewater for irrigation.

6.1. Background on Constructed Wetlands

Generally speaking, constructed wetlands systems are manmade wetlands that are designed to mimic the vegetative and hydraulic conditions found in natural wetlands. These conditions include: (1) areas dominated by hydrophytes (at least periodically), (2) areas with predominantly undrained, hydric soils (wet enough for long enough to produce anaerobic conditions that limit the types of plants that can grow), and (3) areas with non soil substrate(such as rock or gravel) that are saturated or covered by shallow water at some time during the growing season (Hammer and Bastian, 1989).

Currently, there are a number of different constructed wetland designs to achieve specific water quality improvements. For the purpose of this discussion, constructed wetland systems are characterized by these principle components: 1) substrates with various rates of hydraulic conductivity, 2) plants adapted to water-saturated conditions; 3) anaerobic substrates with water flowing in or above the surface of the substrate; and 4) both aerobic and anaerobic microbial populations (Hammer and Bastian, 1989).

Generally, two types of constructed wetland systems are seeing widespread use and success in North America and abroad. These are the free water surface(FWS) systems and the subsurface flow or root zone(SF/RZ) system. Cross sections of the FWS and SF/RZ systems is provided in Figure 6 (WPCF, 1990). Figure 7 is a table of the water purifying processes observed in constructed wetland systems (Stowell, 1980). Each of these systems, or a combination of the two, are being used to treat municipal wastewaters effectively and improve water quality in the receiving surface waters.

Free Water Surface Systems

The free water surface wetland typically consists of a basin or channels with a subsurface barrier to prevent seepage, soils to support the roots of emergent vegetation, and water at a relatively shallow depth flowing through the system. The water surface, in this case, is exposed to the atmosphere, and the flow path through the system is horizontal (Reed 1993). Water purification processes in FWS systems include plant uptake, microbial activity on submerged plant surfaces, and some adsorption to wetland soils. FWS systems are currently operated in Iron Bridge, Lakeland, and Orange County, FL., Incline Village, NV, Iselin, PA, Listowel, Ontario, and Arcata, CA. to name but a few. The major advantages of the FWS systems are lower installation costs and simpler hydraulic properties when compared to the SF/RZ systems (WPCF, 1990).

Subsurface Flow/Root Zone Systems

The subsurface flow (SF) wetland also consists of a basin or channel with a barrier to prevent seepage, but the bed contains a suitable depth of permeable material, such as gravel rather than soil, through which water flows. The media also supports the root structures of the emergent vegetation (Reed, 1993). Filtration, adsorption, and chemical transformations are optimized as the effluent percolates through the substrate and is exposed to microbial activity on the plant's root surfaces. Both nitrification and denitrification in the root zone occur as the plant roots supply oxic microsites to an otherwise anaerobic environment.

In the United States, there are currently more than 130 such wetland systems in operation. Worldwide, another 500 systems are being used with success in Germany, Denmark, Austria, Belgium, France and the United Kingdom (Kadelec, 1992). Advantages of subsurface flow systems include odor minimization, reduced insect vectors, reduced exposure to humans and animals, and successful performance in cold weather climates.

6. 2 Water Purifying Processes in Constructed Wetlands

Constructed wetland systems provide a number of water purifying mechanisms, as outlined in Figure 7 above. The efficiency of the various treatment mechanisms often varies depending on the type of wetland system selected—FWS of SF/RZ. However, given the treatment needs for a constructed wetland system to polish Missoula's wastewater for eventual land application, three treatment mechanisms warrant closer inspection. These are nitrogen, phosphorous, and pathogen removal.

Nitrogen Removal

A number of nitrogen removal processes have been well documented in constructed wetland systems, including plant uptake, soil adsorption, sedimentation, and denitrification. However, review of the available literature clearly demonstrates that nitrification/denitrification is the predominant nitrogen removal mechanism.

The nitrification/denitrification cycle involves a complex series of biochemical reactions facilitated by microbial populations on the roots and stems of wetland vegetation. The cycle is intimately related to the aerobic and anaerobic conditions in wetland soils and root zones. In the nitrification process, nitrifying bacteria oxidize ammonia(NH_3) to nitrite(NO_2) and nitrate(NO_3), respectively (Davido, 1989). The process is driven by aquatic plants that pump oxygen to the root zone below the soil and water surface, providing oxidized zones for nitrification in an otherwise anaerobic environment.

Once ammonia has been converted to nitrite and nitrate, denitrification can occur within the wetland system. Denitrification is accomplished by faculative bacteria that convert nitrite and nitrate to nitrogen gas and nitrous oxide in anaerobic environments (Faulkner, 1989). These gases are then released to the atmosphere. This process is the dominant form of nitrogen treatment in constructed wetlands and is a sustainable, long-term mechanism for removal.

The efficiency of nitrogen removal by these processes varies depending on the vegetation selected, design of the wetland system, and seasonal temperature variations. Studies from a system in Santee, CA show that vegetation selection plays a critical role in nitrogen removal efficiencies. In beds of the same depth, bullrushes removed 94% of applied nitrogen, while reeds, cattails, and unvegetated beds achieved 78%, 28%, and 11% removal respectively (Geresberg, 1985). In a database review of performance of nearly 100 constructed wetland systems, researchers found that nitrogen removal efficiencies vary anywhere from 20% to 90% (Knight, et al., 1993). Based on this review, however, Reed noted that nitrogen removal efficiencies of up to 79% can be expected (Reed et al. 1995)

<u>Phosphorous Removal</u>

Phosphorous removal in constructed wetland systems occurs through a number of processes, including adsorption, absorption, complexation, and precipitation. The dominant mechanisms for phosphorous immobilization in constructed wetland systems appears to be adsorption on to soil particles and plant uptake. Soils with a high clay content and high levels of iron (Fe) and aluminum (Al) are particularly well suited for adsorption because of their large surface area and ability to bind tightly with free phosphorous molecules.

The wetland database mentioned above also provided overall performance data on phosphorous removal, and showed that varying degrees of phosphorous removal have been observed. Reed (1995) suggested that phosphorous removal of 30-50% can be expected in a properly designed wetland. Additionally, studies have indicated constructed wetlands can be effective at immobilizing phosphorous if their internal removal mechanisms are optimized to do so (Richardson, 1987).

Researchers at the constructed wetlands system in Listowel, Ontario saw initial phosphorous removals up to 98%. However, they cautioned that removal efficiencies are expected to decline over the long-term since there is no permanent escape mechanism for phosphorous. Additionally, Richardson and Nichols reported that releases from dying vegetation may result in a net export of 35% to 75% of the phosphorous incorporated into plant tissues (Richardson and Nichols, 1985).

From the long-term perspective, it is important to consider that unlike the denitrifying process for nitrogen removal, phosphorous stays in the overall system. Adsorption sites in the wetland substrate are limited and eventually reach capacity, and phosphorous stored in plant tissues is ultimately discharged from the wetland when the vegetation dies and decomposes. Additionally, soils with high clay content generally have low permeability which limits wastewater contact with the soil matrix. Therefore, while short-term phosphorous removals can be expected, long-term removal efficiencies should be assumed to be less than ten percent.

Disinfection/Pathogen Removal

Constructed wetland systems have shown a demonstrated ability to remove pathogens, including fecal coliform bacteria, from municipal wastewater. The removal of pathogens in wetland systems comes in a variety of ways, including dieoff from exposure to sunlight, predation, sedimentation, and adsorption. Studies at the FWS constructed wetland in Arcata, CA showed fecal coliform removal rates of 95% and virus removal rates of 92%, based on 3 day residence time (Reed, 1995). Significant fecal coliform removal was also observed at the FWS constructed wetland in Listowel, Ontario. These and other studies have shown that hydraulic residence time and temperature are both particularly important for effective fecal coliform removal.

It's interesting to note that researchers reported difficulties quantifying removal efficiencies fecal coliform because birds and mammals using the wetlands contribute their own load of fecal coliform.

6. 3 Constructed Wetland Design Considerations

The performance of any constructed wetland system depends on the system hydrology as well as other factors. Precipitation, infiltration, evapotranspiration, hydraulic loading rate, and water depth can all affect the removal of organics, nutrients, and trace elements not only by altering the retention time, but also by either concentrating or diluting the wastewater (USEPA, 1988). All of these factors must be integrated with the water quality improvements desired and the physical setting in question before a successful constructed wetland can be engineered. Some of the most critical design criteria are discussed below.

A. Wastewater Characterization

The most important consideration for any constructed wetland system is the composition of the incoming effluent, and the treatment levels desired to meet water quality goals in the receiving surface waters. Carbonaceous biological oxygen demand (CBOD), total suspended solids(TSS), nitrate/nitrite/ammonia, soluble phosphorous, and trace metals are all concerns in domestic wastewater.

Concentrations of these compounds in the discharged effluent, and their subsequent impacts on the biological integrity of the receiving waters is the fundamental reason for employing constructed wetland technologies. However, if these systems are to be effective, specific goals for effluent treatment levels must be established so that the system design can maximize the processes to achieve them. In the case of a constructed wetland system for polishing Missoula's wastewater, it's important to note that the wetland will be treating an effluent that has already undergone secondary treatment and disinfection.

B. Vegetation Selection

Vegetation selection is also an important aspect of designing a constructed wetland system. Interactions between the plants, the soil substrate, and the wastewater itself are the primary mechanisms of water quality improvement. Therefore, the plants selected must be able to grow successfully in a wide range of climates and conditions.

For wastewater treatment purposes, the plants selected must meet several or all of the following criteria: (1) be active vegetative colonizers with spreading rhizome systems, (2) have considerable biomass or stem densities to achieve maximum translocation of water and assimilation of nutrients, (3) have maximum surface area for microbial populations, (4) have efficient oxygen transport into the aerobic root zone to facilitate oxidation of reduced toxic metals and support a large rhizosphere, and (5) be a combination of species that will provide coverage over the broadest range of water depths envisioned for the terrain conditions. (Allen et al). The plant species most commonly selected to meet these criteria are cattails (*Typha*, spp.), bulrushes (*Scirpus*, spp.), sedges (*Carex*, spp.), and reeds (*Phragmites*, spp.).

C. Substrate

Substrate soil composition is another important consideration in constructed wetland design. The substrate supports vegetation, provides surface area for microorganism attachment, and is associated with the physical and chemical treatment mechanisms of the constructed wetland. In addition, substrate-water and substrate-root interfaces are critical for development of aerobic-anaerobic treatment mechanisms (Steiner 1989).

Substrate soils are also a critical consideration when determining the eventual fate of the wastewater discharged into the system. In many cases, native soils are more permeable than desired, allowing an increased vertical flow component, decreased control of flow regimes, and increased threats to local groundwater supplies. For this reason, many constructed wetland systems utilize clay or synthetic liners to reduce problems associated with permeable substrates.

D. Wetland Hydrology

The capability of a constructed wetland to treat wastewater efficiently is directly related to the hydrology of the system. Hydraulic loading rate, hydraulic residence time, and water depth are the fundamental components in the design of an effective constructed wetland system.

Hydraulic loading rate (HLR) is a measure of the volume of water applied per unit area of wetland, and is often expressed in cubic meters per hectare per day (cu. m/ha/d) or million gallons per day per acre (mgd/acre). Optimal loading rates must be developed to assure proper wetland function and efficient use of available land for water treatment.

Hydraulic residence time (HRT) is the amount of time it takes a unit of water to pass through the entire wetland system. Longer residence times improve treatment by allowing greater interaction between the wastewater and wetland plants and soils in the system. However, a balance must be reached between the optimal residence time for treatment and the land required to treat the given volume of water. Residence times for the majority of wetlands reviewed ranged from three to seven days.

E. Compartmentalization

Compartmentalization is an important design criteria for many constructed wetland systems because they allow for optimization of different processes in the different cells of the system. The use of multiple cells allows redistribution of flows, maintenance of plant communities, and isolation from different plant populations and any associated diseases or pathogens. Cells arranged in parallel offer flexibility for rotation of discharge sites and major maintenance activities such as harvesting and replanting (WPCF, 1990).

These basic mechanisms that control movement and treatment of water in the constructed wetland system are fairly well understood, and planners and engineers can apply that understanding to optimize the treatment processes depending on the type of wastewater treatment needed. This flexibility in design is one reason so many municipalities are moving to constructed wetland systems.

6.4 Previous Constructed Wetland Evaluations for Missoula

The City of Missoula has already evaluated constructed wetland systems as a treatment option for the future. The first study was conducted during the TD&H report discussed previously. In that analysis, TD&H estimated that Missoula would need a free water surface wetland of 366 acres or a subsurface flow wetland of 210 acres to provide adequate treatment of the MWWTP's 9 mgd wastewater design flow. However, the report concluded that the constructed wetland option would be difficult to implement because of land requirements, the limited ability of wetlands to remove phosphorous, and strict Nondegradation limits on surface and groundwater quality that would receive the wetland discharge.

Brown&Caldwell also conducted an evaluation of constructed wetland systems in the 201 Planning Process. In that analysis, Brown&Caldwell modified the land requirements suggested in the TD&H report. In their assessment, Brown&Caldwell estimated that the minimum acreage for a constructed wetland system would be between 450 to 580 acres for a free water surface wetland, and 380 acres for a subsurface flow wetland capable of treating 9 mgd. For the 20 year horizon, they estimated over 800 acres(FWS) and 500 acres(SSF) wetlands would be needed to treat the 12.6 mgd of wastewater expected at the WWTP in the year 2015. Interestingly, Brown&Caldwell's discussion did not explain why their estimated land requirements were so much higher than those previously provided by TD&H.

Based on these estimates, Brown&Caldwell estimated it would cost Missoula over $116 million to implement the constructed wetland option. They concluded that complete reliance on natural systems may not be feasible due to the vast land area requirements and the phosphorous removal limitation of constructed wetlands. It's interesting to note that Brown&Caldwell did recommend further evaluation of wetland systems as a supplemental or "polishing" approach to divert wasteloads from the Clark Fork River during the summer months. However, that recommendation is based on the assumption that wetlands treatment would only occur after tertiary treatment at a BNR facility.

Both of these evaluations were based on the assumption that the constructed wetland system would have to reduce the wastewater plant's nutrient load down to the VNRP target loads without additional removal from subsequent land application.

6.5 Feasibility of a Constructed Wetland/Land Application System for Missoula

Unlike the constructed wetland evaluations conducted in the past, I propose using a constructed wetland system to polish Missoula's wastewater discharge in order to increase the likelihood that local irrigation companies would accept the wastewater in their ditch systems.

The following feasibility analysis has been conducted to provide a preliminary evaluation of the constructed wetland/land application option for Missoula. Cost estimates are based on existing studies already conducted for the City of Missoula, and preliminary estimates provided by professionals in the wastewater treatment field. It is certainly expected that Missoula would conduct a more detailed cost and feasibility analysis on this proposal. Nonetheless, the following discussion clearly demonstrates that the constructed wetland/land application could be more cost effective than the BNR upgrade currently favored by Missoula's consultants, engineers, and elected officials.

Characterization of Missoula's Effluent

The Missoula Wastewater Treatment Plant currently produces a relatively high quality effluent with their activated sludge secondary treatment system. Figure 8 contains a summary of effluent quality data for a number of parameters monitored in the MWWTP discharge, including BOD, TSS, nitrogen and phosphorous loading and concentrations (MWWTP, 1998).

Figure 9 shows that the average monthly load for carbonaceous biochemical oxygen demand (cBOD) in Missoula's effluent was about 250 pounds per day. Average cBOD concentrations in the effluent were about 4 mg/L. Figure 10 shows an average monthly TSS load of about 400 pounds per day, with an average effluent concentration 6 mg/L.

Figure 11 shows the average total nitrogen (total keldjahl nitrogen plus nitrite/nitrate) load in Missoula's effluent averages a little over 1,000 pounds per day, with an average effluent concentration of about 20 mg/L. This 20 mg/L average is significantly less than the 28 mg/L effluent nitrogen concentration used by Brown&Caldwell in their analysis of land application for the 201 planning process.

For the purposes of wetlands treatment and land application, it's important to distinguish between the various forms of nitrogen present in the discharge. Figure 12 shows that the ammonia fraction of the total nitrogen budget varies seasonally, with summertime concentrations averaging about 5 mg/L and wintertime concentrations closer to 12 mg/L. Figure 13 shows the nitrite/nitrate concentrations in the effluent averaging about 6 mg/L since 1995. The relationship between these two fractions of the nitrogen budget are important planning consideration for constructed wetland design because it is generally desirable to convert as much as possible of the ammonia nitrogen to nitrate prior to constructed wetland treatment and land application.

Figure 14 shows the WWTP averages a monthly phosphorous load of about 100 pounds per day, well below the 375 pound per day discharge permit limit. Figure ? shows that the effluent phosphorous concentrations averaged about 3.5 mg/L historically. In 1994, however, Missoula began experimenting with biological nutrient removal at the WWTP. This has resulted in a marked decrease in effluent phosphorous concentrations, which now average about 2.5 mg/L.

In addition to these parameters, Missoula also conducts occasional sampling for metals content in their treated effluent. Figure 15 shows the results of samples collected over the past three years. These data show that Missoula's effluent generally has very low metals concentrations, with levels of arsenic, cadmium, lead, and mercury at or below detection limits. These data suggest excess metals loading should not be a major concern associated with land application of Missoula's effluent.

Lastly, as part of their MPDES permitting requirements, Missoula also monitors concentrations of fecal coliform bacteria in the effluent during the summer months. Figure 16 shows that the amount of fecal coliform bacteria present in the wastewater discharge can vary by orders of magnitude from week to week, and even day to day. For example, the sample collected August 5, 1996 contained only 20 fecal colonies per 100 milliliters, while the sample collected only two days later contained over 21,000 colonies.

Similarly, during the week of September 22, 1998, fecal counts fluctuated from 15,900 on the 22nd down to 60 on the 23rd, and back up to 10,400 on the 24th.

These highly variable results are attributed to the fact WWTP operators vary the dosage rates of sodium hypochloride—the current disinfecting agent—in attempt to strike a balance between maximizing effective pathogen "kill" while minimizing residual chlorine in the discharged effluent. Generally, speaking WWTP operators vary the hypochloride dosage rate depending on the fecal colifom counts observed on the previous day. The result is highly variable fecal coliform counts in the discharged effluent

Based on the effluent quality observed over the past five years, and the various regulations governing land application of municipal wastewater, it appears effluent nitrogen concentrations and fecal coliform bacteria levels are the two potentially limiting factors for implementing the land application option. Specifically, nitrogen concentrations may limit the volume of wastewater that can be applied per acre while still protecting groundwater quality, and fecal coliform levels may limit the types of distribution and spray systems used to apply the wastewater.

To address these concerns, and to facilitate the land application option, Missoula should consider the following treatment scenario in order to allow summertime discharge of the effluent to the local irrigation ditches for subsequent reuse.

Step 1: Continued Secondary Treatment at the MWWTP

Missoula would continue to provide secondary treatment of the municipal wastewater at the Missoula WWTP. The plant has performed well over the past decade, and plant operators have been recognized for their ability to consistently produce a high quality effluent, even as wastewater loading has increased. In the future, expansions beyond the wastewater treatment plant's current 9 mgd design capacity will be necessary. However, the costs of increasing the plant's capacity to provide secondary treatment of more wastewater would be considerably less than expansions needed to accommodate biological nutrient removal for the same volume.

Step 2: UV Light Disinfection

The next step in the proposed treatment process would be to change the plant's disinfection system from sodium hypochloride contact to a UV light disinfection system. UV light is a nonchemical disinfection system that uses an extremely rapid physical process to destroy pathogens. Specifically, the effluent is passed through UV light chambers where microorganisms are bombarded with light energy of a specific wavelength (240-260 nanometers). Exposure to the high intensity light destroys the microorganisms ability to reproduce, thus providing reliable and efficient disinfection. The effectiveness of UV light disinfection is controlled by the quality of the treated effluent, and its ability to transmit light. Parameters that affect this ability include TSS, soluble BOD, and color.

UV light disinfection is becoming an increasingly attractive option for municipalities for a number of reasons, including: 1) UV light systems can be designed to consistently produce an effluent with fecal coliform counts of less than 200 colonies per 100 milliliters; 2) UV light is a nonchemical disinfection system that eliminates residual chlorine and the formation of trihalomethanes in the discharged effluent; 3) UV light disinfection eliminates the need to transport, store, and handle dangerous chemicals such as chlorine gas; and 4) UV light disinfection systems generally have very low operation and maintenance costs.

Discussions with Aquionics—a designer and distributor of UV light disinfection systems—indicate Missoula's municipal wastewater discharge is an excellent candidate for a UV light disinfection system. The relatively low concentrations of BOD and TSS in the plant effluent indicate it would respond very well to UV light disinfection. Preliminary design and cost estimates for Missoula have been provided based on a very similar system that Aquionics recently designed for the community of Silverton, OR. (Personal Communication, Mike Blake of Aquionics).

Blake estimated that a UV light disinfection system capable of effectively treating an average 12.6 mgd of effluent (26 mgd peak flow) would cost approximately $500.000. This estimate includes about $400,000 for the necessary equipment—including UV lamps and power supply—and about $50.000 for construction and labor. Based on this design, Missoula's treated effluent would meet or exceed 200 fecal coliform colonies per 100 milliliters (geometric average), the level required for Class D reclaimed wastewater (as defined in the Missoula Health Code).

UV light disinfection is an important aspect of this proposal for two reasons. First, disinifection performance will be more consistent, which should address concerns associated with bacteria and viruses present in the land applied wastewater. Second, UV light disinfection eliminates concerns over excess chlorine build up in the soils of the irrigated pastures, and potential impacts on microbial processes.

Step 3: Effluent Polishing in a Constructed Wetland System

After secondary treatment at the WWTP and UV light disinfection, the effluent would be delivered to a constructed wetland system for polishing. For the design analysis which follows, it is assumed that the WWTP will continue to produce an effluent quality consistent with what has been achieved over the past five, including: 1) total nitrogen concentrations of approximately 20 mg/L; 2) phosphorous concentrations of approximately 4 mg/L; 3) BOD and TSS concentrations of less than 10 mg/L; and 4) fecal coliform counts of 200 colonies per 100 ml (assuming an upgrade to UV light disinfection).

Based on these assumptions, the overall treatment goal for the wetland will be a 50% reduction of total nitrogen, a 50% reduction in fecal coliform counts, and nominal reductions for phosphorous. The system will be designed to effectively treat 12.6 mgd—the expected WWTP flow in the year 2015.

Reducing nitrogen concentrations in the effluent is important for two reasons. First, nitrogen loading to groundwater is often the limiting factor when designing a land application system due to concerns over impacts to groundwater quality below the irrigated pastures. Second, it is recognized that some of the wastewater that is delivered to the ditch system may not be used for irrigation. Reducing nitrogen concentrations prior to discharge to the ditch will ultimately reduce nitrogen loading to the Clark Fork River if a portion of the irrigation water is unused and returns to the river. Reducing fecal coliform counts is needed to help satisfy land application guidelines and regulations with minimal operational changes for existing irrigators.

After establishing these treatment goals, I contacted Mr. Michael Ogden, a professional engineer with the Southwest Wetlands Group for guidance on developing preliminary design and cost estimates for a constructed wetland system capable of meeting these treatment needs. The Southwest Wetlands Group (SWG) is a licensed firm that provides specialized engineering services in the area of biological wastewater treatment systems using constructed wetland systems. SWG has provided design, engineering, and construction oversite on more than 125 constructed wetland systems throughout the United States, including cold weather climates similar to Montana.

Mr. Ogden provided a far different cost estimate for a constructed wetlands for Missoula's wastewater treatment needs than that provided by Brown&Caldwell. Mr. Ogden's preliminary estimates, which would certainly need refinement if a detailed design analysis were desired, found that Missoula could use a 130 acre free water surface constructed wetland to treat 12.6 mgd of wastewater to the quality mentioned above. This estimate is based on a hydraulic loading rate of 1 mgd effluent per 10 acres of wetland. This hydraulic loading rate is higher than the average loading rate of 1mgd per 25 acres seen at constructed wetlands across the country (Watson, 1989). However, this loading rate is not unreasonable because it is recognized that higher loading rates are appropriate for wetlands designed to polish already treated wastewater, rather than providing primary or secondary treatment of municipal watewaters. Assuming this hydraulic loading rate, wastewater residence time in the wetland will be approximately 4-5 days.

Mr. Ogden also estimated that, based on his experience, wetland construction costs would range between $25,000 and $50,000 per acre. These costs include earthwork, effluent distribution systems, and vegetation planting. This price range depends on whether there was sufficient native clay material available to line base of the wetland, or if an impermeable liner would need to be installed. This estimated cost per acre is well within range of costs observed at other wetlands, which generally range between $10,000 and $70,000 per acre with an average of about $30,000 per acre (Reed, 1995). Based on this estimate, the cost of building the 130 wetland be between $3.25 and $6.5 million

The one cost not included in this estimate is that for purchasing the land on which the wetland will be built. The Brown&Caldwell 201 Facilities Plan assumed an average land cost of 5,000 per acre. Using that estimate, land acquisition costs would be approximately $650,000. It will be important for Missoula to look for lands immediately adjacent to the WWTP in order to minimize the costs of transporting the treated wastewater to the wetland system. Possible wetland sites could include the "Clark Fork floodplain lands" and the "airport property" identified in the Land&Water Report.

Based on these general estimates, construction of a 130 acre FWS wetland system (including land) would be approximately $4 million to $7.5 million, considerably less than the $33 million estimated in the Brown&Caldwell analysis. Once the wetland was constructed, Missoula would also have to build an effluent pumping system to move the water from: 1) the WWTP to the constructed wetland; and 2) from the wetland to the local irrigation ditches. When designing the delivery system to transport the effluent from the WWTP to the constructed wetland, it will be important to maximize turbulence and /or aeration in order to reduce ammonia concentrations in the effluent through nitrification and/or volatilization. This will be helpful because constructed wetlands are more efficient at removing nitrates than ammonia due to the anaerobic conditions in the wetland.

As for the effluent discharged from the wetland, Missoula should consider building two systems. one from the wetland to the irrigation ditch for discharge during the summertime, and the other from the wetland to the Clark Fork River for the remainder of the year. This will allow polished wastewater to be diverted from the river during the irrigation season, and discharged to the river during the nonsummer months when the VNRP limits are not in effect.

Cost estimates for these pumping system will vary depending on the distance from the WWTP to the wetland, and from the wetland to the irrigation ditch and river. However, cost estimates presented in the TD&H Report indicated that a system to deliver 9 mgd of water from the WWTP to the Flynn/Lowney (Hellgate) Irrigation Ditch would cost approximately $1.25 million. Given the fact that the estimate was made in 1990, and that this proposal would require pumping over greater distances, an estimate of $5 million may be more appropriate.

Given these estimates, it appears Missoula could design and construct a wetland system—including land purchases and an effluent distribution system—for approximately $10-15 million dollars. For that investment, Missoula would get a system that discharges polished wastewater with approximately 10 mg/L total nitrogen, 3-4 mg/L phosphorous, and less than 100 fecal coliform colonies per 100 ml, depending on fecal contributions from waterfowl and wildlife that may use the wetland.

Step 4: Discharge to Local Irrigation Ditches

The final step in this proposed wastewater management scenario is to discharge the polished effluent to local irrigation ditches. The first choice would be the Flynn Lowney (Hellgate) Irrigation ditch, which flows immediately adjacent to the WWTP. The Flynn-Lowney Ditch currently has water rights for 42 cfs of water, which they divert from the Clark Fork River a few miles upstream of the WWTP. Water users serviced by this ditch irrigate approximately 2000 acres of land downstream of the WWTP. Sprinkler irrigation is almost exclusively used, and alfalfa and grass hay are the crops grown (Clause and Flynn, personal communication).

Review of soil maps generated by the USGS and SCS show that the soil types on the lands serviced by the Flynn/Lowney (Hellgate) Ditch are all suitable for land application of wastewater. These soil types—which include the DeSmet loam series, the Grantsdale loam series, and the Moiese gravelly loam—were all identified in Dr. Inskeep's report as potentially suitable soil types for land applying wastewater.

Water Quality Characterization for Land Applied Effluent

The constructed wetland system described above is specifically designed to improve the quality of Missoula's WWTP effluent so that the Flynn/Lowney Ditch Company will allow Missoula to use the existing irrigation ditch and sprinkler systems for land application. Assuming successful attainment of the wetland treatment objectives discussed above, the polished wastewater that is actually delivered to the ditch should contain approximately 10 mg/L nitrogen, 3 mg/L phosphorous, and 100 fecal coliform colonies per 100 ml.

Under this proposed scenario, the ditch company would reduce the amount of water they divert from the river by the amount of polished effluent discharged from the wetland system. To estimate the quality of the water that would ultimately be applied to the irrigated crops, it is important to consider that significant dilution of the polished effluent will occur in the ditch itself. The following table estimates the amount of dilution that water in the ditch will provide.

	WWTP Flow	Diversion needed to supply 42 cfs to ditch	Dilution ratio
Current	11.6 cfs	30. 4 cfs	2.5 : 1
Design	13.9 cfs	28.1 cfs	2 : 1
Year 2015	19.3 cfs	22.4 cfs	1 : 1

As this table shows, the dilution effect in the ditch will decrease over time as flows from the WWTP continue to increase with population growth. However, even in the year 2015, it can be expected that the river water in the ditch will decrease nitrogen, phosphorous, and fecal coliform concentrations by as much as one half. This dilution effect must be considered in the nutrient loading analysis and regulatory review of the land application option.

Based on this polishing and dilution scenario, the final quality of the water actually applied to the irrigated pastures could be expected to have the following parameters: 1) total nitrogen concentrations of 5-10 mg/L; 2) total phosphorous concentrations of 2-3 mg/L; and 3) fecal coliform bacteria counts of less than 50 colonies per 100 ml. Assuming these conditions, it is then possible to estimate nitrogen and phosphorous loading rates to the irrigated pastures served by the Flynn/Lowney (Hellgate) Irrigation Ditch.

As mentioned above, the Flynn/Lowney ditch has water rights to 42 cfs of water, and irrigates approximately 2,000 acres of alfalfa and grass hay crops. Discussions with representatives from the ditch company indicate there is some degree of uncertainty as to exactly how much water the irrigators apply to these crops. However, nitrogen and phosphorous loading rates can estimated using: 1) nitrogen and phosphorous concentrations in the land applied water; 2) the approximate volume of water applied to the crops; 3) and the number of acres the water is applied to.

The following estimate of nitrogen and phosphorous loading is based on the following assumptions: 1) total nitrogen concentrations 5 to 10 mg/L; 2) total phosphorous concentrations of 2-3 mg/L; and 3) 20 to 40 cfs of water is applied to 2000 acres of pasture served by the ditch. Also note that a conversion factor of 8.34 is used to convert flow (mgd) and concentration (mg/L) to pounds per day. This conversion factor is used by both the MWWTP and Brown&Caldwell in their loading analysis.

Flow (mgd) x conc. (mg/L) x 8.34 = #'s/day x 120 days / 2000 acres = #'s/acre/yr.

Estimated Nitrogen Loading

26 mgd (40 cfs) x 10 mg/L N x 8.34 = 2168#'s/day

2168#'s/day x 120 = 260,208#'s / 2000 = **130#'s/acre/yr**

26 mgd (40 cfs) x 5 mg/L N x 8.34 = 1084#'s/day

1084#'s/day x 120 = 130,104#'s / 2000 = **65#'s/acre/yr**

19.5 mgd (30 cfs) x 10 mg/L N x 8.34 = 1626#'s/day

1626#'s/day x 120 = 195,120#'s / 2000 = **98#'s/acre/yr**

19.5 mgd (30 cfs) x 5 mg/L N x 8.34 = 813 #'s day

813#'s/day x 120 = 97,5873#'s / 2000 = **48#'s/acre/yr**

13 mgd (20 cfs) x 10 mg/L x 8.34 = 1,084#'s/day

1,084#'s/day x 120 =130,080#'s / 2000 = **65#'s/acre/yr**

13 mgd (20 cfs) x 5 mg/L N x 8.34 = 542#'s/day

542#'s/day x 120 = 65,052#'s / 2000 = **33#'s/acre/yr**

<u>Estimated Phosphorous Loading</u>

26 mgd (40 cfs) x 3 mg/L P x 8.34 = 650#'s/day

650#'s/day x 120 =78,000#'s / 2000 = **39#'s/acre/yr**

26 mgd (40 cfs) x 2 mg/L P x 8.34 = 434#'s/day

434#'s/day x 120 = 52,080#'s / 2000 = **26#'s/acr/yr**

19.5 mgd (30 cfs) x 3 mg/L P x 8.34 = 488#'s/day

488#'s/day x 120 = 58,560#'s / 2000 = **29#'s/ acre/yr**

19.5 mgd (30 cfs) x 2 mg/L x 8.34 = 325#'s/day

325#'s/day x 120 = 39,000#'s / 2000 = **20#'s/acre/yr**

13 mgd (20 cfs) x 3 mg/L x 8.34 = 325#'s/day

325#'s/day x 120 = 39,000#'s / 2000 = **20#'s/acre/yr**

13 mgd (20 cfs) x 2 mg/L x 8.34 = 217#'s/day

217#'s/day x 120 = 26,040#'s / 2000 = **13#'s/acre/yr**

These analyses shows that nitrogen and phosphorous loading rates to irrigated pastures should range between 30-130 pounds nitrogen per acre per year and 13-39 pounds phosphorous per acre per year, depending on removal efficiencies in the constructed wetland system, dilution capacity in the irrigation ditch, and final water application rates used by the local irrigators. Even if the highest loading rates are assumed, nitrogen loading will be well below the 216 pounds per acre estimated in Inskeep's analysis.

For phosphorous, maximum loading rates are higher than the 26 pounds per acre suggested by Inskeep. However, this should not be problematic because Inskeep noted that grass and alfalfa crops would utilize nearly all of the phosphorous applied, and because phosphorous loading to groundwater is not considered a concern from a regulatory standpoint. It's also important to note that these increased nutrient concentrations in the irrigation water will actually provide an economic benefit to the irrigators in the form of free fertilizer. Actual estimates of savings in fertilizer costs may vary, but the economic benefit of applying the polished wastewater is real.

A final consideration in the analysis is compliance with regulations and guideline for municipal wastewater reuse. The proposed wastewater management scenario will significantly reduce fecal coliform in the land applied effluent by combining UV light disinfection with polishing in a constructed wetland system. Fecal coliform counts in the land applied water can be expected to be less than 50 colonies per 100 ml. This should help to minimize restrictions imposed on reuse of the wastewater.

In fact, the wetland effluent would likely meet Class C reclaimed wastewater requirements adopted by Missoula County. Missoula County would have to make the final determinations on the classification of the land applied effluent, and any restrictions that may come with it. Regardless, upgrading to a UV light disinfection system, polishing in a constructed wetland, and dilution with river water in the ditch should all help to minimize restrictions on land applying the polished effluent.

This discussion clearly demonstrates that land applying MWWTP effluent after polishing in a constructed wetland and dilution in the Flynn-Lowney ditch is a wastewater management option that can work for both the City and the irrigators. The City benefits by diverting their discharge from the river during the summer months which will result in compliance with the instream nutrient targets established in the VNRP at a cost considerably less than those estimated in the Draft 201 Facilities Plan. Moreover, the irrigation companies can benefit by reducing costs for diverting water from the river to the ditch, and free fertilizer in the water they apply to their fields.

7.0 Discussion

The preceding analysis clearly demonstrates that Missoula could implement the constructed wetland/land application option to meet their current and future wastewater needs. However, several important questions must be addressed as Missoula considers the implementability of the land application option.

- What happens if irrigators don't use all of the water discharged to the ditch?
- How will Missoula secure access to the land application sites?
- What happens if the constructed wetland doesn't work well in the winter?
- How will the ditch companies existing water rights be affected ?

A discussion of these important issues follows.

<u>Water Use</u>

One of the major concerns associated with relying on land application for Missoula's future wastewater needs is that lands that are currently under irrigation may be subdivided in the future. Several City and County officials have indicated that they don't want Missoula to invest in the facilities needed for land application, only to realize ten years from now that the land they planned to deliver the water to is no longer available. This is a valid concern.

Under the constructed wetland/land application scenario, the polished wastewater would be delivered to the Flynn/Lowney ditch for use by existing irrigators. Even with current irrigation practices, however, some of the water that is diverted from the Clark Fork is not used, and eventually exits the ditch and returns to the river just upstream of Council Hill. The amount of return flow has not been quantified. Given this current situation, it is only reasonable to assume that a portion of the polished and diluted wastewater would continue to return to the Clark Fork in the future.

This situation, however, is not a fatal flaw for the constructed wetland/land application option for three important reasons. First, as the analysis above indicates, the final quality of water flowing through the ditch—after polishing and dilution—is expected to be approximately 5-10 mg/L total nitrogen and 1-2 mg/L total phosphorous. This return flow will be of similar or better quality than the water that the proposed BNR system will discharge to the river. Recall that Brown&Caldwells preliminary designs are based on producing an effluent with 10 mg/L nitrogen and 1 mg/L phosphorous.

Second, he Flynn/Lowney joins the Field/Dougherty ditch about two miles west of the WWTP and discharges to the Clark Fork just upstream of Council Hill. Therefore, using the ditch system to transport the water changes the discharge point of Missoula's wastewater from the existing treatment plant to about three miles further downstream. In the VNRP modeling efforts to predict the necessary nutrient load reductions, the Subcommittee found that the Clark Fork between the MWWTP and the confluence of the Bitterroot was the most difficult reach of river for Missoula to meet the instream targets. Quite simply, the braided channels and lower stream flows in that reach provided less dilution capacity than the mainstem downstream of the Bitterroot confluence. However, using the ditch system moves the discharge point downstream, and nearly eliminates wastewater impacts to the most sensitive reach of the river.

Third, this discharge point is less than a half mile upstream of, and on the same side of the river as the diversion dam for the Grass Valley ditch, which divert some 100 cfs of water for irrigation in the western end of the Missoula valley. It seems very safe to assume that some, if not all of the water discharged from the Flynn Lowney ditch will be diverted from the river into the Grass Valley ditch. Therefore, impacts to the river from the return flow should be negligible.

Securing Access to the Irrigated Land

The second major concern with the land application option was the cost of purchasing the land to irrigate with wastewater. Under the constructed wetland/land application option, the water would simply be delivered to the ditch after secondary treatment, disinfection, polishing, and dilution. Missoula would obviously need to enter in to some sort of long-term agreement with the ditch company to assure they would accept the wastewater in the future. The simplest way to do so would be through a written agreement between the two parties.

However, WQB-2 guidelines may require some sort of lease agreement on the irrigated land itself. An attractive way to secure access to the irrigated lands would be to enter into agricultural conservation easements with the various land owners who use the ditch system. Agricultural conservation easements are agreements that allow irrigators to continue using their land as they currently do, but prevents subdivision of those lands during the timeframe of the lease agreement. Currently, there are local, state, and federal programs that are using various form of agricultural conservation easements to keep agricultural lands in production. At the local level, the Five Valleys Land Trust has an active program that seeks to maintain some of the agricultural character of the Missoula Valley. In fact, they just recently entered into an agricultural conservation easement with one of the ranchers on the Grass Valley Ditch. Five Valley is interested in securing more of these easements, and are willing to consider lands currently served by the Flynn/Lowney Ditch in their future efforts.

At the state level, governor Racicot recently announced plans for a bill that would appropriate $4 million dollars for purchasing similar easements on agricultural lands in Montana. The purpose of this program is also to help maintain some of Montana's agricultural character. If approved by the Legislature, these funds could be used to help purchase easements on irrigated lands served by the Flynn/Lowney ditch.

Finally, at the national level, three agencies in the US Department of Agriculture—the Natural Resources Conservation Service, the Forest Service, and the Farm Service Agency—are all actively pursuing conservation of agricultural lands in the U.S. In particular, the NRCS has initiated the Farmland Protection Program which provides matching funds for easement purchases by state and local governments. It provides $35 million for the purchase of up to 340,000 acres of farmland protection easements through the year 2002.

These program all provide creative ways to secure access to irrigated pastures without having to purchase the land outright, and they should be pursued as a way to facilitate land application in and preserve agricultural lands here in the Missoula Valley.

Wetland Performance in Cold Weather

A concern with the constructed wetland/land application option is wetland performance during the winter months. Experiences at a number of constructed wetlands in cold climates has found that removal efficiencies tend to drop off in the winter months as colder temperatures slow the rate of microbial processes in the wetland system. Consequently, Missoula should not expect the wetland system to work as well during the cold winter months.

Fortunately, this should not be a problem for the constructed wetland/land application option because the wastewater polishing is only needed during the irrigation season when the wastewater will be delivered to the ditch system. Estimated removal efficiencies presented in this analysis are based on performance during the summer months. However, I recommend Missoula discharge their effluent to the wetland system on a year round basis. This would allow some level of nutrient removal during the entire year, and would also allow additional research on the performance of constructed wetland systems during the colder winter months.

Water Rights

A final consideration in the constructed wetland/land application option consideration is how the existing water rights of the ditch companies would be affected if they reduce the amount of water they divert from the river. As the Prior Appropriations Doctrine goes, water rights holders must use their water, or they lose their right to it.

To address this issue, I propose that the ditch companies negotiate an instream flow lease for the water they will not divert from the river due to augmentation of flows with the WWTP effluent. Instream flow leasing programs were approved by the Montana Legislature in 1995, and could be used in this situation. One potential scenario would be for the City of Missoula, the Montana Department of Fish, Wildlife, and Parks, or another interested party to lease the excess water from the ditch company for instream flows. Leaving the 10 to 20 cfs of water in the river will provide nominal benefits to the river in the form of increased flows for dilution and overall water quality improvements from reduced algae growth. Consequently, the party would lease the water from the ditch company for a nominal fee, and the ditch company would retain their rights to the water not diverted. If in the future, the ditch company decided they were no longer interested in taking effluent from the WWTP, their full water rights would still be in effect.

8.0 Conclusion

The preceding discussion clearly demonstrates that a constructed wetland/land application system could be a viable option to meet Missoula's future wastewater needs. Moreover, based on the preliminary cost estimates presented, it should be possible to implement this option for considerably less than the BNR upgrade currently favored by the City's consultants, engineers, and elected officials.

I believe Missoula should carefully evaluate this option as part of the 210 Planning Process for two reasons. From a regulatory standpoint, the constructed wetland/land application option will meet Missoula's obligations under the VNRP because the WWTP discharge will be diverted from the river during the summer months. More importantly, from a community perspective it will provide a number of ancillary benefits to valley residents that the proposed BNR facility will not. These include creation of wetland habitat, preservation of open spaces, maintenance of the agricultural character of the western part of the valley, and unique educational and recreational opportunities for the valley residents.

Moreover, rather than spending money on more concrete, steel, and electricity at the WWTP, the constructed wetland/land application option presents an opportunity to invest in the future of Missoula. At the constructed wetland system in Arcata, CA, for example, designers included a system of trails around the wetland so residents could enjoy the wildlife and waterfowl that use the wetland. Additionally, an interpretive center was included to accommodate educational opportunities and scientific research. The result? Over 150,000 people a year visit the wetland system for passive recreation and scientific study.

Similarly, the community of Silverton, Oregon is moving forward with their own plans to utilize a constructed wetland system to meet their growing wastewater treatment needs. At that project, 23 acres of constructed wetlands will be incorporated into the Oregon Gardens—which will include educational exhibits on the diversity and value of wetland habitat. During the summer months, water that is treated in the wetland system will then be used for general irrigation purposes. City consultants estimate that the newly created Oregon Gardens will attract upwards of 400,000 visitors a year. There is no reason Missoula couldn't include similar design components in a constructed wetland system here.

9.0 Recommendations

Based on this conclusion, I recommend the City of Missoula take two steps towards determining the feasibility of the constructed wetland/land application option. The first is to hire the Southwest Wetlands Group to conduct a more detailed analysis of design and cost considerations for a wetland system to polish Missoula's wastewater. Mr. Ogden estimated that the SWG could conduct such an analysis for approximately $5,000. Given the fact that Missoula will spend tens of millions of dollars implementing the 201 Plan in the future, spending $5,000 to see if we can meet our wastewater treatment needs for much less cost seems like a very wise investment of taxpayer dollars.

Second, Missoula should begin discussions with representatives from the Flynn/Lowney Ditch Company to determine their level of interest in the project. In the course of researching this paper, I have spoken at length with Mike Flynn (president) and Harvey Clause (secretary) of the ditch company. Both indicated they would be more than willing to sit down and discuss this proposal in greater detail, and Missoula should not hesitate to do so.

References Cited

Bahls, L.L., 1993. ***Periphyton bioassessment methods for Montana streams***. Montana Department of Health and Environmental Sciences—Water Quality Division. Helena, MT.

Blake, M., 1998. Personal communication with Mike Blake, Aquionics. Erlanger, KY. November, 1998.

Brown&Caldwell, 1997. ***Draft 201 Facilities Plan for Missoula, MT***.

Clause, H. and Flynn, M., 1998. Personal Communication with Harvey Clause and Mike Flynn—secretary and president of Flynn/Lowney Irrigation Ditch Company, October, 1998.

Davido, R.L. and T.E. Conway 1989. ***Nitrification and Denitrification at the Iselin Marsh, Pond, Meadow Facility***. In Constructed wetlands for wastewater treatment: municipal, industrial, and agricultural. Proceedings from the First International Conference on Constructed Wetlands for Wastewater Treatment held in Chattanooga, TN on June 13-17, 1988. Lewis Publishers, 1989.

ES&T, 1998. ***The Emergence of Treatment Wetlands***. In Environmental Science & Technology / News, 218-223. May, 1998.

Faulkner, S.P. and C.J. Richardson 1989. ***Physical and Chemical Characteristics of Freshwater Wetland Soils.*** In Constructed wetlands for wastewater treatment: municipal, industrial, and agricultural. Proceedings from the First International Conference on Constructed Wetlands for Wastewater Treatment held in Chattanooga, TN on June 13-17, 1988. Lewis Publishers, 1989.

Geresberg, R.M., B.V. Elkins, S.R. Lyons, and C.R. Goldman 1985. ***Role of Aquatic Plants in Wastewater Treatment by Artificial Wetlands***. Water Res. 20:363-367. 1985

Hammer, D.A. and R.K. Bastian 1989. ***Wetland Ecosystems: Natural Water Purifiers?*** In Constructed wetlands for wastewater treatment: municipal, industrial, and agricultural. Proceedings from the First International Conference on Constructed Wetlands for Wastewater Treatment held in Chattanooga, TN on June 13-17, 1988. Lewis Publishers, 1989.

Hasler, A.D. 1947. ***Eutrophication of lakes by domestic drainage***. Ecology, 28:338-395.

Horner, R.R., et al., 1983. ***Development of nuisance periphytic algae in laboratory streams in relation to enrichment and velocity***. p. 121-134. In: Wetzel, R.G. (ed.) Periphyton of Freshwater Ecosystems. Dr. W. Junk Publishers, The Hague.

Ingman, G.M., 1992. ***Assessment of Phosphorous and Nitrogen Sources in the Clark Fork River Basin, 1988-1991, Final Report***. Section 525 of the Clean Water Act Ammendments. Montana Department of Environmental Health and Sciences, Helena, MT. January 1992.

Ingman, G.M., 1992b: ***A rationale and alternatives for controlling nutrients and eutrophication problems in the Clark Fork River Basin***. Section 525 of the Clean Water Act Amendments. Montana Department of Health and Environmental Sciences—Water Quality Bureau. Helena, MT. June, 1992.

Johnson, H.E. and Schmidt, C.L., 1988. ***Clark Fork Basin Project—Status Report and Action Plan***. Office of the Governor. Helena, MT. December, 1988.

Kadelec, R.H. 1992. ***Constructed Wetlands for Wastewater Treatment***. Paper presented at Creating and Using Wetlands Conference. Department of Engineering Professional Development, University of Wisconsin, Madison, Wisconsin. May 4-6, 1992.

Karr, J.R. and Dudley, D.R., 1981. ***Ecological perspectives on water quality goals***. Environmental Management 5:55-68.

Knight, R.L., et al, 1993. ***Wetlands for Wastewater Treatment: Performance Database***. In Constructed Wetlands for Water Quality Improvement. Gerald A. Moshiri(editor). CRC Press, 1993. ISBN 0-87371-550-0.

Land&Water Consulting, Inc., 1995. ***Preliminary Information on Potential Wastewater Application Sites and Clark Fork Water Quality Issues***. Land&Water Consulting, Inc. P.O. Box 8254, Missoula, MT 59807.

Lang-Bertalot, H., 1979. ***Pollution tolerance of diatoms as a criterion for water quality estimation***. Nova Hedwigia 64:285-304.

Likens, 1972. ***Eutrophication and Aquatic Ecosystems***. In Nutrients and Eutrophication, The American Society of Limnology and Oceanography, Inc. Allen Press, Inc. Lawrence, KS. 1972.

MCCHD, 1997. ***Wastewater Reclamation and Reuse Requirements***. Missoula City County Health Department. Missoula, MT 1997.

McGuire, D.L., 1995. ***Clark Fork River Macroinvertebrate Community Biointegrity: 1993 assessment***. For the Montana Department of Environmental Quality—Water Quality Division by McGuire Consulting. Helena, MT. April, 1996.

McGuire, D.L., 1996. ***Clark Fork River Macroinvertebrate Community Biointegrity: 1994 assessment***. For the Montana Department of Environmental Quality—Water Quality Division by McGuire Consulting. Helena, MT. April, 1996.

MDHES, 1990. ***Montana Water Quality-The 1990 305(b) Report***. Montana Department of Health and Environmental Sciences, Helena, MT. June, 1990.

MDHES, 1995. ***Circular WQB 2—Design Standards for Wastewater Facilities***. Montana Department of Environmental Health and Sciences. Helena, MT 1995 Edition.

MWWTP, 1998. ***Missoula Wastewater Treatment Plant Discharge Monitoring Report***. Monthly monitoring report to Montana Department of Environmental Quality Quality. October, 1998.

Missoula Independent, September, 3 1998.

NAS, 1969. ***Eutrophication: Causes, Concequences, and Correctives***. National Academy of Sciences. Book Number 309-01700-9. Washington, DC 1969.

Ogden, M., 1998. Personal Communication with Mr. Michael Ogen, Southwest Wetlands Group. October, 1988.

Personal Communication with Dave Clark, September, 1998. HDR Engineering (Consultant to the City of Missoula on 201 Facility Plan), 1161 W. River Street, Boise, ID 83707-2245.

Plafkin, J.L. et al. 1989. ***Rapid bioassessment protocols for use in streams and rivers: benthic macroinvertebrates and fish***. USEPA/444/4-89-001.

Reed, S.C., E.J. Middlebrooks, and R.W. Crites 1993. ***Design of Subsurface Flow Constructed Wetlands***. In Natural Systems for Waste Management and Treatment, 2nd Edition. McGraw Hill , New York, NY. 1993.

Reed, S.C., E.J. Middlebrooks, and R.W. Crites 1995. ***Natural systems for Waste Management and Treatment***. Second Edition. McGraw-Hill, Inc. 1995. ISBN 0-07-060982-9.

Richardson, C.J., and D.S. Nichols, 1985. ***Ecological Analysis of Wastewater Management Criteria in Wetland Ecosystems***. In Ecological Considerations in Wetlands Treatment of Municipal Wastewaters. Van Nostrand Reinhold Co. 1985.

Richardson, C.J. and J.A. Davis 1987. ***Natural and Artificial Wetland Ecosystems: Ecological Opportunities and Limitations***. In Aquatic Plants for Wastewater Treatment and Resource Recovery. K.R. Reddy and W.H. Smith, Eds. Magnolia Publishing, Orlando, FL 1987, 819-854.

SAIC, 1994. ***Development of Clark Fork River Nutrient Wasteload Allocations***. Prepared by Science Applications International Corporation, McLean, VA. EPA Contract Number 68-C3-0303. April, 1994.

Smith, V.H. and Dodds, W.K., 1995. ***Managing excess chlorophyll levels in the Clark Fork River with nutrient controls***. A report presented to the Montana Department of Health and Environmental Sciences. February, 1995.

Stowell, R., R. Ludwig, J.Colt, and G. Tchbanoglous, 1980. ***Toward the Rational Design of Aquatic Treatment Systems***. Department of Civil Engineering, University of California, Davis, CA August, 1980.

TD&H, 1991. ***Land Application of Wastewater—Phase 1 Preliminary Assessment for Missoula, MT.*** Thomas, Dean, and Hoskins Engineering Consultants. March, 1991.

TSIC, 1998. ***Clark Fork River Voluntary Nutrient Reduction Program***. Tri-State Implementation Council—Nutrient Target Subcommittee. Sandpoint, ID. August, 1998.

WRS, 1960. ***Water Resources Survey—Missoula County, Montana***. Published by the State Engineers Office, Helena, MT. June, 1960

Watson, T.J. and J.A. Hobson 1989. ***Hydraulic Design considerations and Control Structures for constructed Wetlands for Wastewater Treatment***. In Constructed wetlands for wastewater treatment: municipal, industrial, and agricultural. Proceedings from the First International Conference on Constructed Wetlands for Wastewater Treatment held in Chattanooga, TN on June 13-17, 1988. Lewis Publishers, 1989.

Watson, V., 1990. ***Control of Algae Standing Crop by P and N in the Clark Fork River***. In Proceedings of the Clark Fork River Symposium. Montana Academy of Sciences. April, 1990.

Watson, V., 1991. ***Evaluation of the Benefits of Nutrient Reductions on Algal Levels in the Clark Fork River***. Final contract report to the Montana Department of Health and Environmental Sciences. June, 1992.

Watson, V. and Gestring, B., 1996. ***Monitoring Algae Levels in the Clark Fork River***. Intermountain Journal of Sciences 2:2:17-26.

Weber, E.E., 1995. ***An assessment of the biological integrity and impairment of aquatic life in the Clark Fork River and its tributaries based on the structure and composition of algae associations in the periphyton community during August 1993***. Prepared for the Montana Department of Environmental Health and Sciences—Water Quality Division. By Phycologic, Eat helena, MT. January, 1995.

Weber, E.E., 1996. ***An assessment of the biological integrity and impairment of aquatic life in the Clark Fork River and its tributaries based on the structure and composition of algae associations in the periphyton community during August 1994.*** Prepared for the Montana Department of Environmental Health and Sciences—Water Quality Division. By Phycologic, Eat helena, MT. June, 1996.

Welch, E.B., et al., 1988. ***Nuisance Biomass Levels of periphytic algae streams***. Hydrobiologia 157:161-168.

WPCF, 1990. ***Natural Systems for Wastewater Treatment***. Water Pollution Control Federation, Technical Practice Committee Control Group. Manual of Practice FD-16.

USEPA, 1981. ***Process Desing Manual for Land Treatment of Municipal Wastewater***. 625/1-81-013. United States Environmental Protection Agency, Center for Environmental Research Information, Cincinnati, OH. October, 1981.

USEPA 1988. ***Constructed Wetlands and Aquatic Plant Systems for Municipal Wastewater Treatment***. United States Environmental Protection Agency, Office of Research and Development. Document #625/1-88/022.

USEPA, 1993. ***Clark Fork-Pend Oreille Basin Water Quality Study—A summary of findings and a Management Plan.*** Conducted Un 'er Section 525 of the Clean Water of 1987. EPA 910/R-93-006.

Figure 1

Percent N and P Contributions by Point Source
(Ingman, 1992)

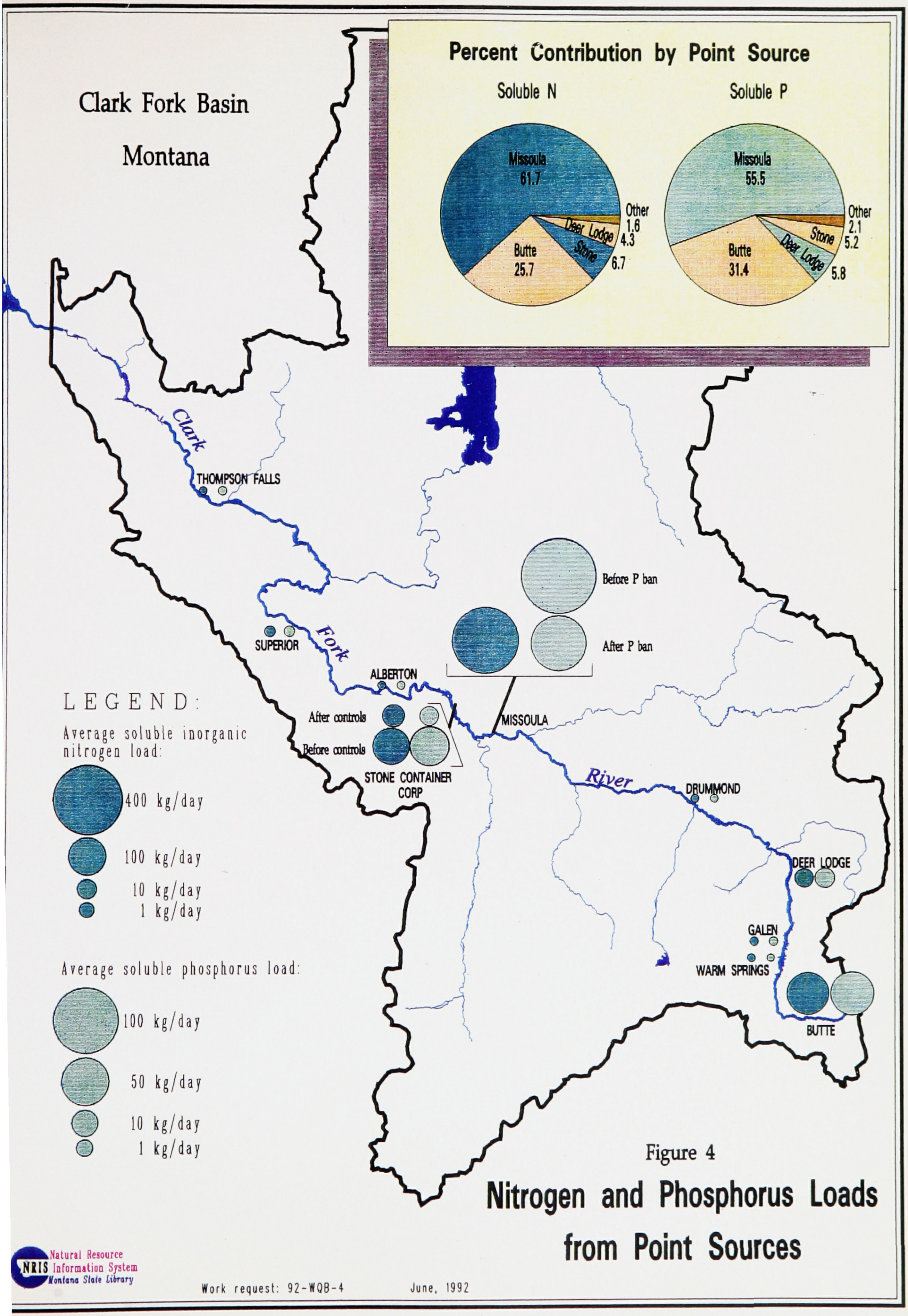


Figure 4

Nitrogen and Phosphorus Loads from Point Sources

Figure 2

Costs for Wastewater Treatment Alternatives
(Brown&Caldwell, 1996)

Summary of Capital and Operations and Maintenance Costs

Alternative Profile	Alternative									
	A Existing	B 1 Central Biological Nutrient	B 2 Central Seasonal Land	B 3 Central with Transfer to Stone Container	B 4 Central Constructed Wetlands	B 5 Central BNR with Filtration	C Satellite	D Dispersed with land costs	D Dispersed without land Costs	
Year 2015 Average Flow, mgd										
Central	11 04	12 66	12 66	12 66	12 66	12 66	11 44	10 73	10 73	
Bitterroot	N/A	N/A	N/A	N/A	N/A	N/A	0 79	N/A	N/A	
O'Keefe Creek	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0 80	0 80	
East Missoula	N/A	N/A	N/A	N/A	N/A	N/A	0 17	0 17	0 17	
Dispersed Land Application Sites	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0 93	0 93	
Total	11 04	12 66	12 66	12 66	12 66	12 66	12 40	12 64	12 64	12 66
Year 2045 Average Flow, mgd										
Central	12 63	18 34	18 34	18 34	18 34	18 34	14 61	12 76	12 76	18 34
Bitterroot	N/A	N/A	N/A	N/A	N/A	N/A	2 18	N/A	N/A	N/A
O'Keefe Creek	N/A	N/A	N/A	N/A	N/A	N/A	0 98	1 89	1 89	N/A
East Missoula	N/A	N/A	N/A	N/A	N/A	N/A	0 64	0 64	0 64	N/A
Dispersed Land Application Sites	N/A	N/A	N/A	N/A	N/A	N/A	N/A	3 08	3 08	N/A
Total	12 63	18 34	18 34	18 34	18 34	18 34	18 41	18 37	18 37	18.34
Estimated 50 Year Cost	$63,217,000	$150,352,000	$163,165,000	$155,953,000	$169,454,000	$162,352,000	$161,311,000	$220,802,000	$169,887,000	$203,797,000
Present Worth of 50-Year Cost	$48,706,000	$69,463,000	$82,469,000	$76,683,000	$101,165,000	$79,089,000	$81,927,000	$118,247,000	$88,199,000	$139,621,000
Relative Magnitude of 50 Year PW	70	100	119	110	146	114	118	170	127	201
Estimated 20 Year Cost	$39,244,000	$94,007,000	$110,574,000	$103,362,000	$116,863,000	$106,007,000	$116,709,000	$172,298,000	$101,712,000	$158,340,000
Present Worth of 20 Year Cost	$46,875,000	$65,348,000	$78,640,000	$76,683,000	$97,336,000	$74,974,000	$78,520,000	$114,542,000	$85,095,000	$136,185,000
Relative Magnitude of 20 Year PW	72	100	120	117	149	115	120	175	130	208
PW of 20 Year Annual O&M	$27,711,000	$34,303,000	$33,057,000	$34,926,000	$34,615,000	$34,926,000	$37,419,000	$35,550,000	$35,550,000	$34,303,103
Total 20 Year PW	$74,586,000	$99,651,000	$111,697,000	$111,609,000	$131,951,000	$109,900,000	$115,939,000	$150,092,000	$120,645,000	$170,488,103
Relative Magnitude of 20 Year PW	75	100	112	112	132	110	116	151	121	171
Comment	Does not allow expanded service area	Single WWTP upgraded to BNR	Seasonal Diversion of nutrient loading	Does not include improvements to Pulp Mill	May not meet Phosphorus removal requirements	Higher level of treatment than Alternative B 1	Land application at E. Missoula Discharge elsewhere	No surface water discharge from dispersed sites	No surface water discharge from dispersed sites	Single WWTP relocated with BNR

Figure 3

Missoula Wastewater Reclamation Requirements
(MCCHD, 1997)

[redacted]: Treatment and Quality Requirements for Reclaimed Water Use

Use	Type of Reclaimed Water Allowed			
	Class A	Class B	Class C	Class D
Irrigation of Nonfood Crops				
Trees and fodder, fiber, and seed crops	yes	yes	yes	yes
Sod, ornamental plants for commercial use, pasture to which milking cows or goats have access	yes	yes	yes	no
Irrigation of Food Crops				
Spray Irrigation				
All Food Crops	yes	no	no	no
Foods crops which undergo physical or chemical processing sufficient to destroy all pathogens	yes	yes	yes	yes
Surface Irrigation				
Food crops where there is no reclaimed water contact with edible portion of crop				
Root Crops	yes	yes	no	no
Orchards	yes	no	no	no
Foods crops which undergo physical or chemical	yes	yes	yes	yes
processing sufficient to destroy all pathogens	yes	yes	yes	yes
Landscape Irrigation				
Restricted access areas (e.g., cemeteries and freeway landscapes)	yes	yes	yes	no
Open access areas (e.g., golf courses, parks, playgrounds, schoolyards, residential landscapes)	yes	no	no	no
Impoundments				
Landscape Impoundments	yes	yes	yes	no
Restricted Recreational Impoundment	yes	yes	no	no
Nonrestricted Recreational Impoundment	yes	no	no	no
Street Cleaning				
Street Sweeping, brush dampening	yes	yes	yes	no
Street Washing, spray	yes	no	no	no
Washing of Corporation Yards/Lots	yes	yes	no	no
Dust Control	yes	yes	yes	no
Fire Fighting and Protection				
Dumping from aircraft	yes	yes	yes	no
Hydrants or sprinkler systems for buildings	yes	yes	no	no
Industrial Boiler Feed	yes	yes	yes	no
Industrial Cooling				
Aerosols and other mist not created	yes	yes	yes	no
Aerosols or other mists created (e.g., use in cooling towers, forced air evaporation, or spraying)	yes	no	no	no
Industrial Process				
Without exposure to workers	yes	yes	yes	no
With exposure to workers	yes	no	no	no

Figure 4

Estimated Consumptive Water Use for Local Crops
(TD&H, 1991)

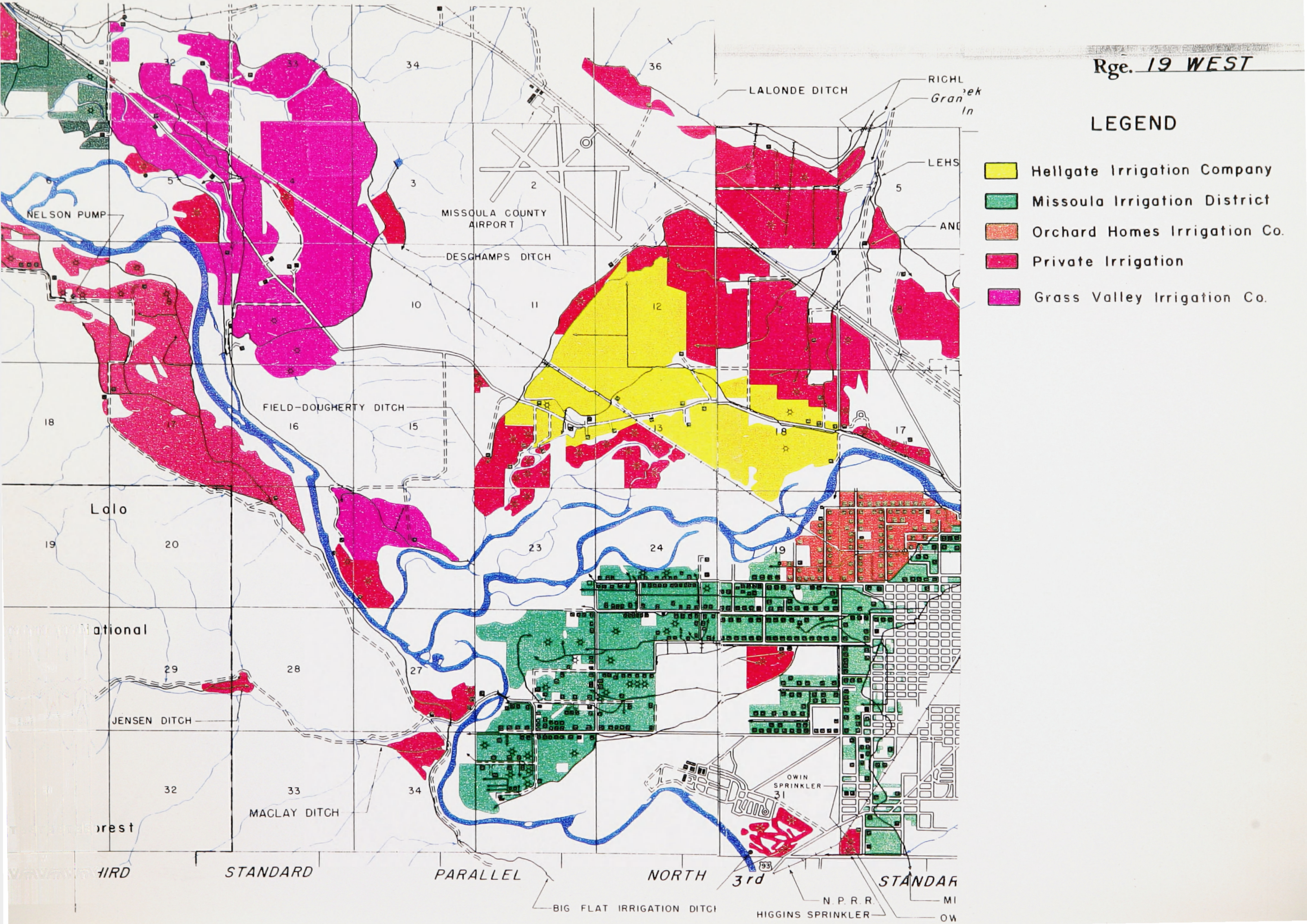
[redacted]. *Estimates of consumptive use and evapotranspiration at the study area (centered on section 11, 13N, 20W)*

	Consumptive Use * (inches)			Evapotranspiration **		
Month	Alfalfa	Grass Hay	Spring Grain	Solar Thermal	Penman	Thornthwaite
Jan-March	-- ***	--	--	0.4	4.3	0.4
April	--	0.8	0.3	1.6	3.5	1.6
May	3.3	3.2	2.7	3.6	5.3	3.1
June	5.6	4.6	6.2	4.6	5.7	4.0
July	7.3	6.2	6.7	7.0	8.1	5.1
August	6.5	5.3	1.2	5.8	7.4	4.7
September	3.3	2.9	--	2.9	4.0	2.8
October	--	0.6	--	1.1	1.8	1.5
Nov.-Dec.	--	--	--	0.1	1.8	0.2
TOTAL	26	24	17	27	42	23

* Balaney-Criddle Method (USDA-SCS)
** MSU MAPS Mail Box Version 3.1
*** No Consumptive Use Is Calculated When There Is No Crop

Figure 5

Lands Served by Local Irrigation Ditches
(WRS, 1960)



Rge. 19 WEST
LEGEND
Hellgate Irrigation Company
Missoula Irrigation District
Orchard Homes Irrigation Co.
Private Irrigation
Grass Valley Irrigation Co.
LALONDE DITCH
NELSON PUMP
MISSOULA COUNTY AIRPORT
DESCHAMPS DITCH
FIELD-DOUGHERTY DITCH
Lolo
National
JENSEN DITCH
MACLAY DITCH
OWIN SPRINKLER
STANDARD
PARALLEL
NORTH
3rd
BIG FLAT IRRIGATION DITCH
N.P.R.R.
HIGGINS SPRINKLER

Figure 6

Cross Section of Constructed Wetland Systems
(WPCF, 1990)

[redacted] Classification of constructed wetland types commonly used for wastewater management.

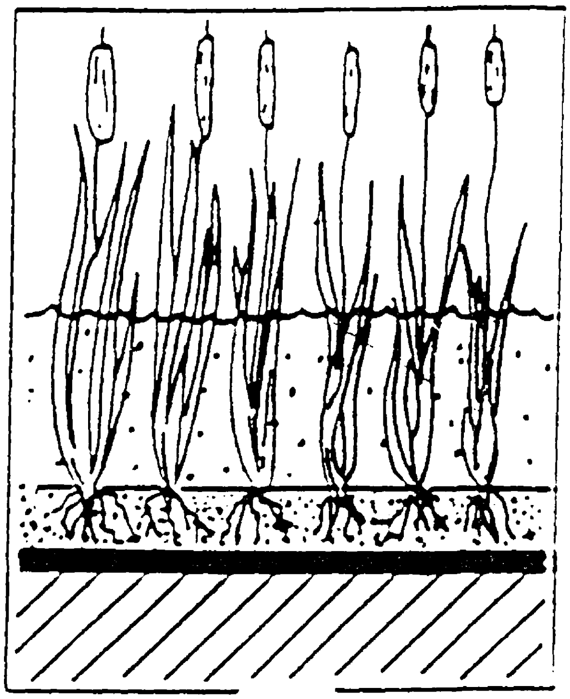
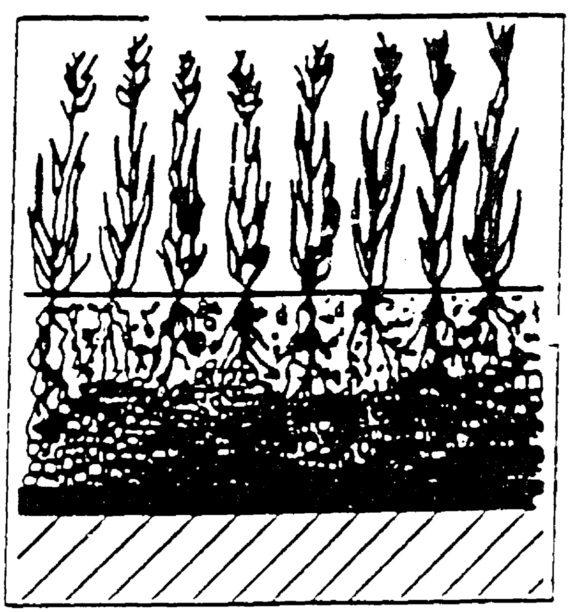
Constructed Wetland Types	Diagram	Description
Free water surface		Water level is above the ground surface; vegetation is rooted and emergent above the water surface; water flow is primarily above ground; vegetation may be planted or allowed to colonize voluntarily.
Vegetated submerged beds		Water level is below ground, water flow is through soil or gravel bed; root penetration is to bottom of bed; wetland plants are generally common reed, bulrush, or cattail.

Figure 7

Water Purifying Processes in Constructed Wetlands
(Stowell, 1980)

[redacted]. **Containment Removal Mechanisms in Aquatic Systems Employing Plants and Animals**

Mechanism	Contaminant Affected[a]	Description
Physical		
Sedimentation	P - Settleable solids S - Colloidal solids I - BOD, nitrogen, phosphorus, heavy metals, refractory organics, bacteria and virus	Gravity settling solids (and constituent contaminants) in pond/marsh settings.
Filtration	S - Settleable solids, colloidal solids	Particulates filtered mechanically as water passes through substrate, root masses, or fish.
Adsorption	S - Colloidal solids	Interparticle attractive force (van der Waals force).
Chemical		
Precipitation	P - Phosphorus, heavy metals	Formation of or coprecipitation with insoluble compounds.
Adsorption	P - Phosphorus, heavy metals S - Refractory organics	Adsorption on substrate and plant surface.
Decomposition	P - Refractory organics	Decomposition or alteration of less stable compounds by phenomena such as UV irradiation, oxidation, and reduction.
Biological		
Microbial metabolism[b]	P - Colloidal solids, BOD, nitrogen, refractory organics, heavy metals	Removal of colloidal solids and soluble organics by suspended, benthic, and plant-supported bacteria. Bacterial nitrification/denitrification. Microbially mediated oxidation of metals.
Plant metabolism[b]	S - Refractory organics, bacteria, and virus	Uptake and metabolism of organics by plants. Root excretions may be toxic to organisms of enteric origin.
Plant absorption	S - Nitrogen, phosphorus, heavy metals, refractory organics	Under proper conditions, significant quantities of these contaminants will be taken up by plants.
Natural dieoff	P - Bacteria and virus	Natural decay or organisms in an unfavorable environment.

Source: Stowell et al.[14]

[a]P = primary effect; S = secondary effect; I = incidental effect (effect occurring incidental to removal of another contaminant).

[b]Metabolism includes both biosynthesis and catabolic reactions.

Figure 8

Summary of MWWTP Effluent Quality Data
(MWWTP, 1998)

MISSOULA WASTEWATER TREATMENT FACILITY

PHOSPHORUS, TOTAL SUSPENDED SOLIDS,
cBOD, AND TOTAL NITROGEN LOADING CALCULATIONS

LIMITS:
PHOSPHORUS: 378# DAY ANNUAL ABERAGE- 4.5MGD
TSS : 2202#/DAY IN A 30 DAY AVERAGE
cBOD : 1877#/DAY IN A 30 DAY AVERAGE

MONTH	AVERAGE MONTHLY FLOW MGD	PHOSPHORUS CONCNTRTN mg/l	PHOSPHORUS (AVERAGE) #/DAY	MARGIN ~ 378#/DAY	TOTAL SUSPENDED SOLIDS mg/l	TOTAL SUSPENDED SOLIDS #/day	cBOD mg/l	cBOD #/day	TOTAL NITROGEN mg/l	TOTAL NITROGEN #/day
1996										
JAN	6.66	2.77	154	221	6.99	388	3.94	219	15.21	845
FEB	7.11	2.19	130	245	7.61	451	4.43	263	20.06	1190
MAR	6.96	0.67	39	336	13.42	779	6.52	378	20.47	1188
APR	7.45	1.21	75	300	12.79	795	5.06	314	16.21	1007
MAY	7.86	2.68	176	199	12.91	846	5.45	357	18.61	1220
JUN	8.70	0.75	54	321	8.47	615	5.94	431	16.29	1182
JUL	7.80	3.32	216	159	5.19	338	2.85	185	14.26	928
AUG	7.13	0.25	15	360	5.15	306	3.76	224	18.12	1077
SEP	6.96	0.20	12	363	4.14	240	2.89	168	21.47	1246
OCT	6.70	1.40	78	297	5.53	309	2.84	159	22.51	1258
NOV	6.88	1.78	102	273	4.72	271	2.80	161	22.05	1265
DEC	6.57	1.90	104	271	6.39	350	3.35	184	26.34	1443
AVG	7.23	1.66	96	279	7.78	474	4.15	254	19.30	1164
1997										
JAN	6.67	2.05	114	261	7.39	411	5.52	307	20.37	1133
FEB	7.18	0.91	54	321	7.50	449	3.38	202	22.61	1354
MAR	7.52	0.62	39	336	9.52	597	2.87	180	19.12	1199
APR	8.26	1.46	101	274	7.53	519	4.30	296	20.64	1422
MAY	7.90	4.18	275	100	9.05	596	4.45	293	14.67	967
JUN	8.87	3.23	239	136	4.82	357	2.96	219	14.77	1093
JUL	8.22	1.95	134	241	5.27	361	4.06	278	14.41	988
AUG	7.99	0.84	56	319	4.56	304	3.25	217	17.57	1171
SEP	7.96	1.59	106	269	4.16	276	3.44	228	17.14	1138
OCT	7.59	0.92	58	317	4.85	307	3.59	227	21.11	1336
NOV	7.20	1.67	100	275	5.61	337	3.59	216	21.22	1274
DEC	7.37	1.96	120	255	5.71	351	3.54	218	17.91	1101
AVG	7.73	1.78	116	259	6.33	406	3.75	240	18.46	1181
1998										
JAN	7.65	3.34	213	162	6.95	443	4.58	292	19.73	1259
FEB	8.19	3.11	212	163	6.38	436	3.76	257	21.18	1447
MAR	7.78	2.80	182	193	7.15	464	4.06	263	20.57	1335
APR	8.40	0.38	27	348	5.56	390	3.58	251	22.41	1570
MAY	8.76	1.52	111	264	7.15	522	3.32	243	19.48	1423
JUN	8.16	2.77	189	186	6.15	420	4.23	289	11.77	803
JUL	8.29	1.34	93	282	4.51	312	3.83	265	10.88	752
AUG	8.26	2.35	162	213	5.33	367	3.70	255	14.88	1025
SEP	8.50	2.35	167	208	4.40	312	4.34	308	16.58	1175
OCT	8.26	0.95	65	310	6.03	415	3.64	251	17.75	1223
NOV				375						
DEC				375					0.00	
AVG	8.23	2.09	143	232	6.96	408	3.90	267	15.93	1201

PREVI
YEA
PHOSPI
LOADI
1981 39
1982 37
1983 NC
1984 30
1985 27
1986 29
1987 297
1988 342
1989 228
1990 180
1991 163
1992 198
1993 180
1994 186
1995 918
PREVIOUS
YEARS
TSS
LOADINGS
1991 7368/
1992 6454/
1993 5278/
1994 6228/C
1995 3868/C
PREVIOUS
YEARS
cBOD
LOADINGS
1991 3708/
1992 3768/C
1993 3908/C
1994 3548/C
1995 2268/C
PREVIOUS
YEARS
TOTAL NITROG
LOADINGS
1992 12308/
1993 11778/
1994 12838/C
1995 10298/C

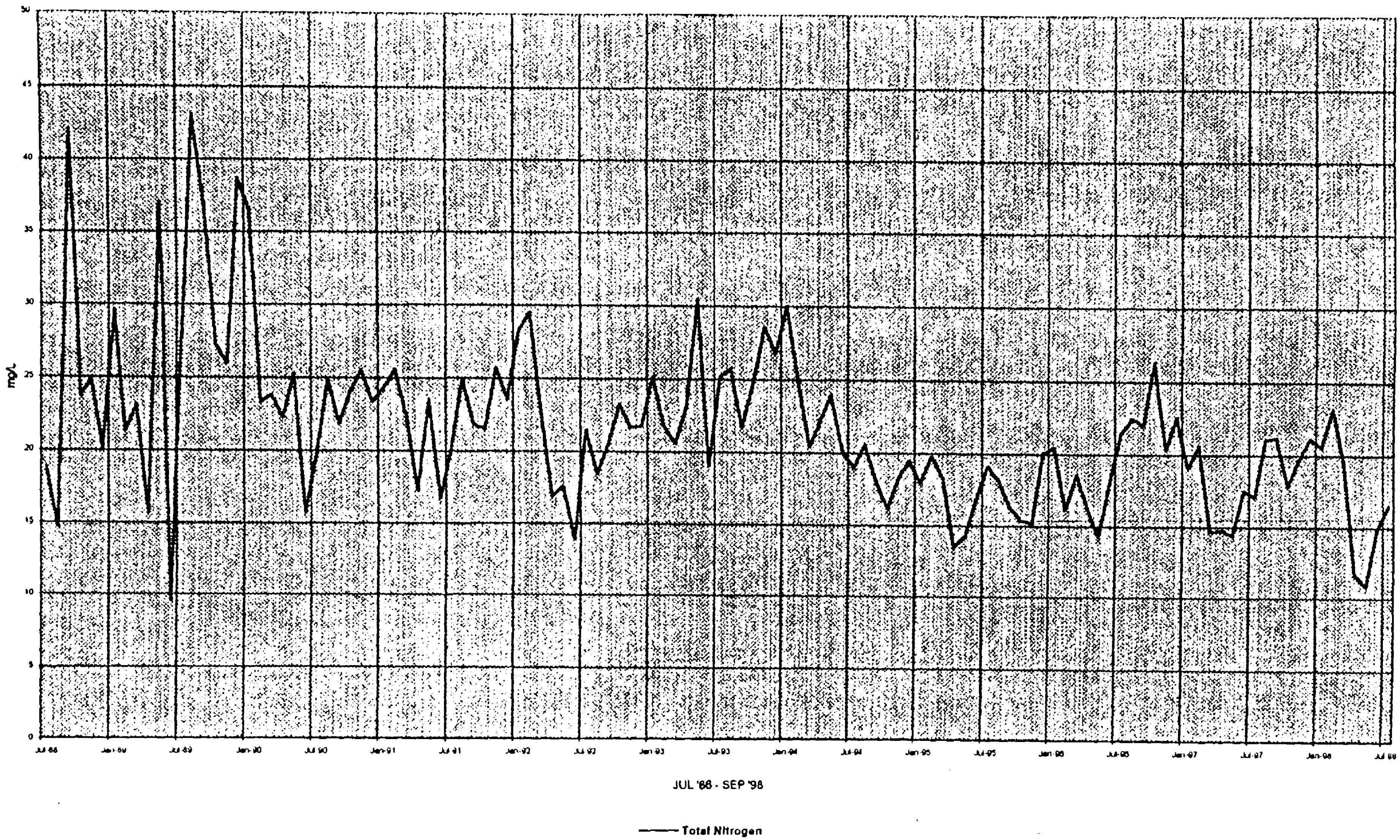
Figure 9

Average cBOD Load from MWWTP
(MWWTP, 1998)

Figure 10

Average TSS Load from MWWTP
(MWWTP, 1998)

MISSOULA WASTEWATER TREATMENT FACILITY
Effluent Total Nitrogen(TKN +NO3-NO2)
Monthly Averages



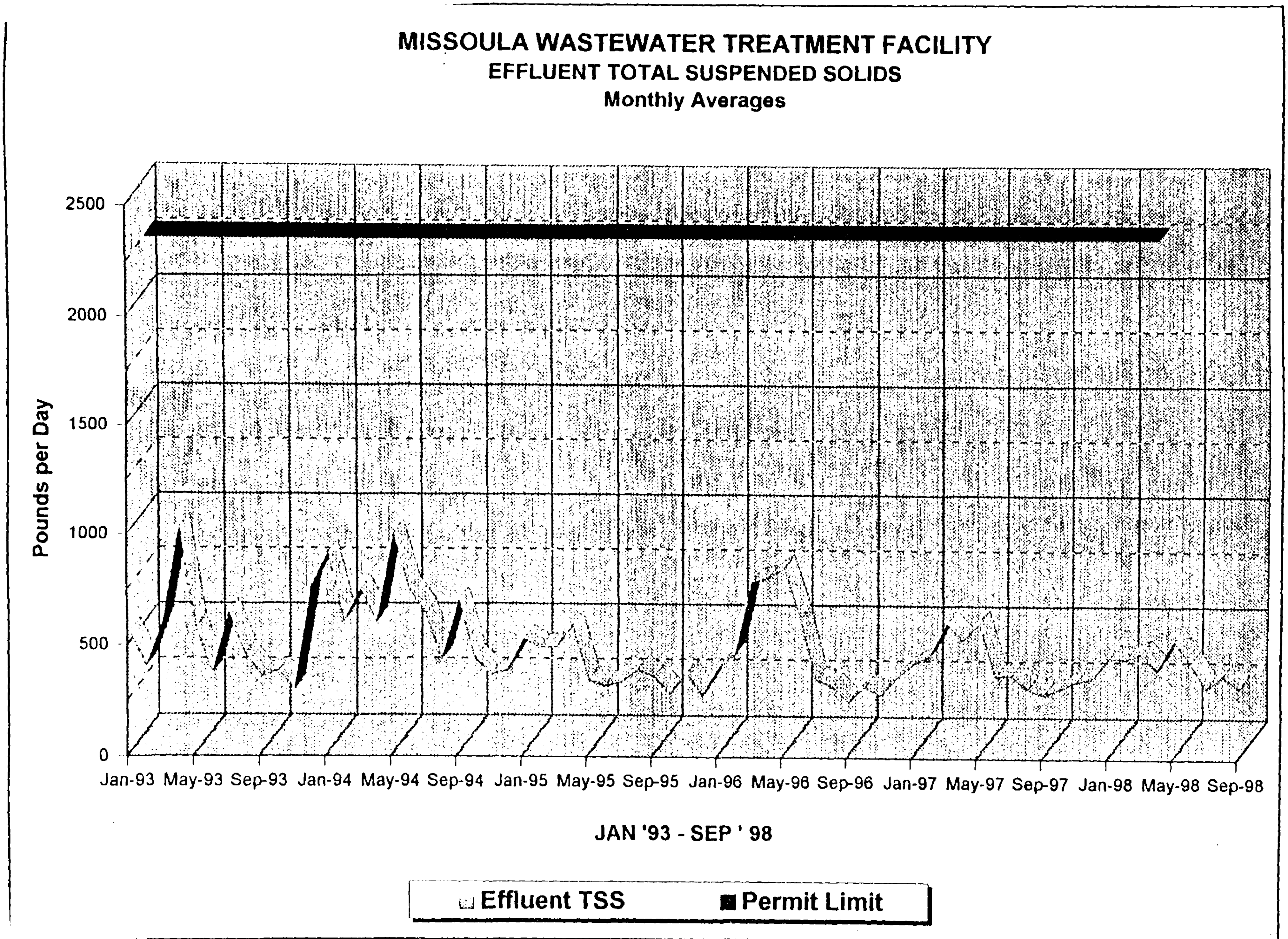

MISSOULA WASTEWATER TREATMENT FACILITY
EFFLUENT TOTAL SUSPENDED SOLIDS
Monthly Averages
Pounds per Day
2500
2000
1500
1000
500
0
Jan-93
May-93
Sep-93
Jan-94
May-94
Sep-94
Jan-95
May-95
Sep-95
Jan-96
May-96
Sep-96
Jan-97
May-97
Sep-97
Jan-98
May-98
Sep-98
JAN '93 - SEP ' 98
Effluent TSS
Permit Limit

Figure 11

Average Total Nitrogen Load from MWWTP
(MWWTP, 1998)

Figure 12

Ammonia Concentrations in MWWTP Effluent
(MWWTP, 1998)

Figure 13

Nitrite/Nitrate Concentrations in MWWTP Effluent
(MWWTP, 1998)

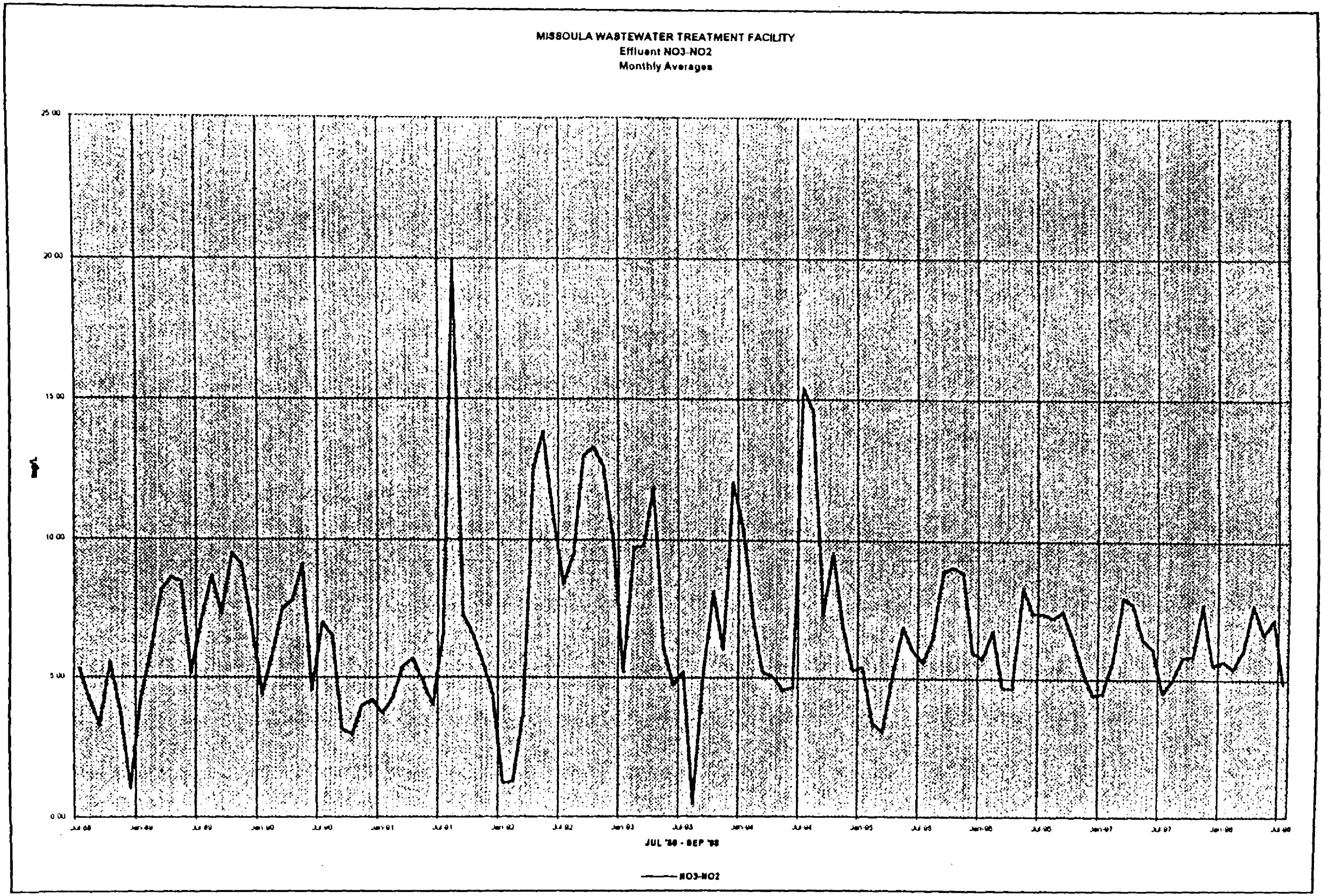
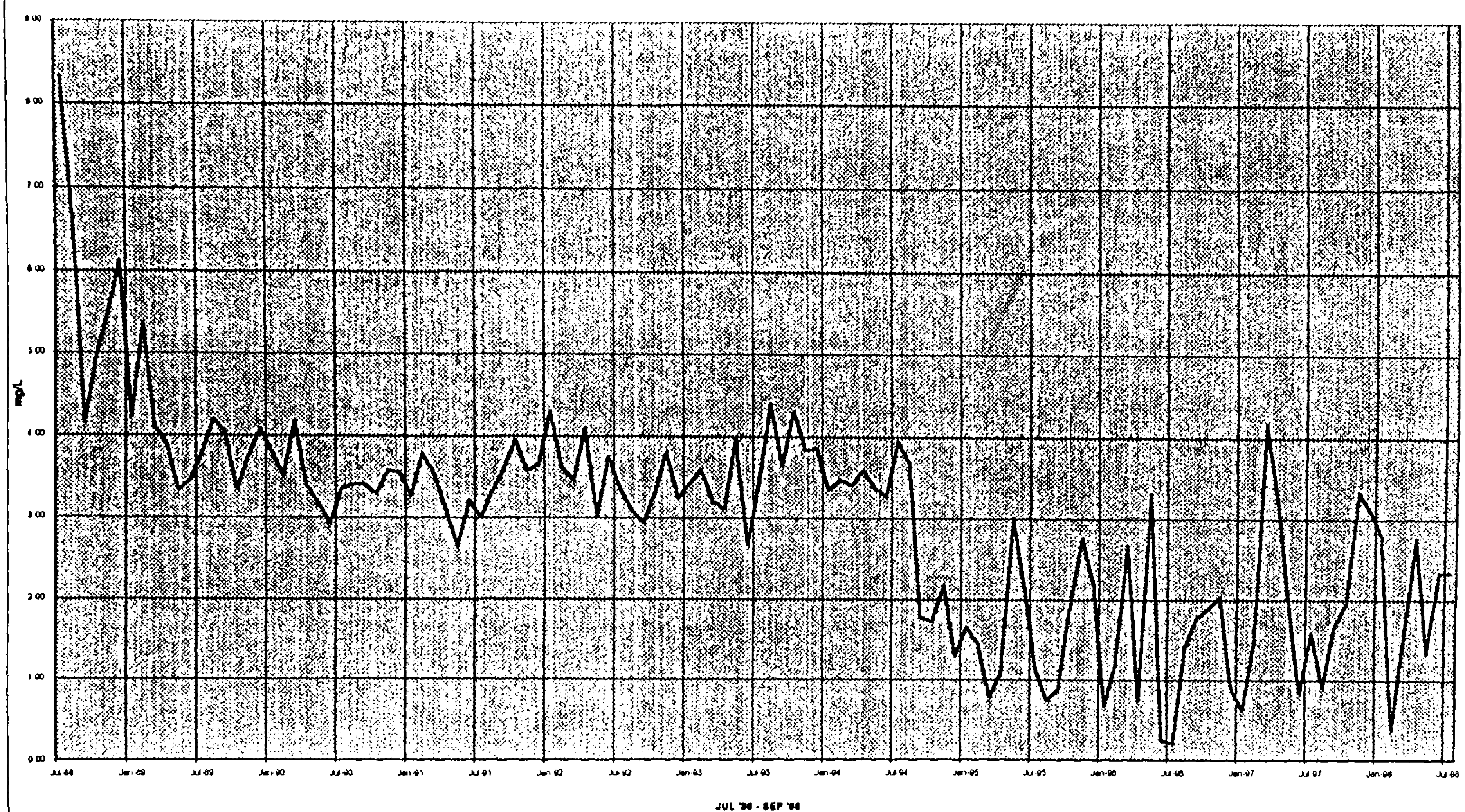

MISSOULA WASTEWATER TREATMENT FACILITY
Effluent NO3-NO2
Monthly Averages
25.00
20.00
15.00
10.00
5.00
0.00
JUL '88 - SEP '98
NO3-NO2

Figure 14

Phosphorous Concentrations in MWWTP Effluent (MWWTP, 1998)

MISSOULA WASTEWATER TREATMENT FACILITY
Effluent Total Phosphorus
Monthly Averages



— Total Phosphorus

Figure 15

Metals Concentrations in MWWTP Effluent
(MWWTP, 1998)

Influent - Effluent - Sludge Metals Testing

Missoula Wastewater Treatment Facility

Influent ≤ *If BDL then 1/2 MDL*

	As	Cd	Cr	Cu	Pb	Hg	Mo	Ni	Se	Ag	Zn
03/18/96	0.0025 <	0.002	0.005 <	0.005 <	0.005 <I	0.0005 <I	0.0025 <I	0.005 <	0.0025 <	0.011	0.16
07/16/96	0.0025 <	0.0005 <	0.005 <	0.1	0.005 <I	0.0005 <I	0.0025 <I	0.005 <	0.0025 <	0.017	0.24
10/24/96	0.0025 <	0.003	0.005 <	0.09	0.02	0.0005 <I	0.0025 <I	0.005 <	0.0025 <	0.039	0.11
12/16/96	0.0025 <	0.0005 <	0.005 <	0.07	0.01	0.0005 <I	0.0025 <I	0.005 <	0.0025 <	0.005 <	0.1
03/18/97	0.0025 <	0.0005 <	0.005 <	0.06	0.01	0.0005 <I	0.0025 <I	0.005 <	0.0025 <	0.009	0.12
05/27/97	0.0025 <	0.0005 <	0.005 <	0.08	0.009	0.00005 <I	0.01	0.005 <	0.0025 <	0.0019	0.21
09/15/97	0.0025 <	0.0005 <	0.005 <	0.07	0.012	0.00005 <I	0.005	0.005 <	0.0025 <	0.0101	0.07
11/24/97	0.0025 <	0.0005 <	0.005 <	0.06	0.005	0.00005 <I	0.0025 <I	0.005 <	0.0025 <	0.0036	0.09
02/02/98	0.0025 <	0.0005 <	0.005 <	0.06	0.007	0.00005 <I	0.006	0.005 <	0.0025 <	0.009	0.1
08/04/98	0.0025 <	0.0005 <	0.005 <	0.07	0.009	0.0004	0.008	0.005 <	0.0025 <	0.0102	0.1
Min	0.0025	0.0005	0.005	0.005	0.005	0.00005	0.0025	0.005	0.0025	0.0019	0.07
Ave	0.0025	0.0009	0.005	0.0665	0.0092	0.00031	0.0044	0.005	0.0025	0.01158	0.13
Max	0.0025	0.003	0.005	0.1	0.02	0.0005	0.01	0.005	0.0025	0.039	0.24

Effluent ≤ *If BDL then 1/4 MDL*

	As	Cd	Cr	Cu	Pb	Hg	Mo	Ni	Se	Ag	Zn
03/18/96	0.00125 <I	0.001	0.0025 <	0.0025 <	0.0025 <	0.00025 <I	0.00125 <	0.0025 <	0.00125 <	0.00125 <	0.06
07/16/96	0.00125 <I	0.00025 <	0.0025 <	0.03	0.0025 <	0.00025 <I	0.00125 <	0.0025 <	0.00125 <	0.00125 <	0.25
10/24/96	0.00125 <I	0.00025 <	0.0025 <	0.0025 <	0.0025 <	0.00025 <I	0.00125 <	0.0025 <	0.00125 <	0.00125 <	0.05
12/16/96	0.00125 <I	0.00025 <	0.0025 <	0.0025 <	0.0025 <	0.00025 <I	0.00125 <	0.0025 <	0.00125 <	0.00125 <	0.04
03/18/97	0.00125 <I	0.00025 <	0.0025 <	0.0025 <	0.0025 <	0.00025 <I	0.00125 <	0.0025 <	0.00125 <	0.00125 <	0.04
05/27/97	0.00125 <I	0.00025 <	0.0025 <	0.0025 <	0.0005 <I	0.000025 <I	0.00125 <	0.0025 <	0.00125 <	0.000125 <	0.03
09/15/97	0.00125 <I	0.00025 <	0.0025 <	0.0025 <	0.003	0.000025 <I	0.00125 <	0.0025 <	0.00125 <	0.0005	0.0025
11/24/97	0.00125 <I	0.00025 <	0.0025 <	0.0025 <	0.0005 <I	0.000025 <I	0.00125 <	0.0025 <	0.00125 <	0.000125 <	0.04
02/02/98	0.00125 <I	0.00025 <	0.0025 <	0.0025 <	0.0005 <I	0.000025 <I	0.00125 <	0.0025 <	0.00125 <	0.0014	0.04
08/04/98	0.00125 <I	0.00025 <	0.0025 <	0.0025 <	0.0005 <I	0.000025 <I	0.008	0.0025 <	0.00125 <	0.0008	0.04
Min	0.00125	0.00025	0.0025	0.0025	0.0005	0.000025	0.00125	0.0025	0.00125	0.000125	0.0025
Ave	0.00125	0.000325	0.0025	0.00525	0.00175	0.0001375	0.001925	0.0025	0.00125	0.00092	0.05925
Max	0.00125	0.001	0.0025	0.03	0.003	0.00025	0.008	0.0025	0.00125	0.0014	0.25
% Reduction	50%	64%	50%	92%	81%	56%	56%	50%	50%	92%	54%

		As	Cd	Cr	Cu	Pb	Hg	Mo	Ni	Se	Ag	Zn
Aquatic Life Comparison of Undiluted Effluent												
Acute Standard	ug/l	360	3.9	16 *	18	82	2.4	NA	1400	20	4.1	120
	mg/l	0.36	0.0039	0.016	0.018	0.082	0.0024		1.4	0.02	0.0041	0.12
Evaluation		OK	OK	OK	Exceeds	OK	OK		OK	OK	OK	Exceeds
Max Percent of Standard		0.3% #	25.6% #	15.6%	166.7% #	3.7% #	10.4%		0.2%	6.3%	34.1% #	208.3%
				*assume hexavalent								
Human Health (Drinking Water)												
Standard	ug/l	18	5	100	1000	15	0.14	NA	100	50	NA	5000
	mg/l	0.018	0.005	0.1	1	0.015	0.00014		0.1	0.05		5
Evaluation		OK	OK	OK	OK	OK	Exceeds *		OK	OK		OK
Max Percent of Standard		6.9%	20.0%	2.5%	3.0%	20.0%	178.6%		2.5%	2.5%		5.0%

Sludge ≤ *If BDL then 1/2 MDL* Dry Basis

	As	Cd	Cr	Cu	Pb	Hg	Mo	Ni	Se	Ag	Zn
03/18/96	2.5 <	4	34.5	x	100	2	11	20.5	2.5 <	125	825
07/16/96	2.8	0.5	4.9	110	23	4.8	1 <I	2	1 <	15	85
10/24/96	2.5 <	2	94	730	120	7	6	22	8	150	870
12/16/96	2.5 <	6	46	760	120	4	2.5 <I	11	10	150	850
03/18/97	6	6	30	600	120	3.6	6	7	6	110	800
05/28/97	2.5 <	5	36	610	110	5	11	20	2.5 <	110	720
06/04/97						0.5 <1					
09/15/97	2.5 <	2	81	700	99	7	8	19	7	150	800
11/24/97	2.5 <	4	310	770	120	4	15	33	6	160	880
02/02/98	3.4	4.1	120	780	120	4.1	13	25	5.5	140	810
08/04/98	4.6	5.3	39	921	117	4.6	13	14	6	123	829
Ave	3.18	3.89	78.54	598.10	104.90	4.24	8.65	17.35	5.45	123.30	746.90
Limit	**41**	**39**	**1,200**	**1,500**	**300**	**17**	**75**	**420**	**36**		**2,800**

BDL = Below Detection Limits MDL = reported Method Detection Limits Results in mg/l

ƷY LABORATORIES, INC.
30916 • 1107 SOUTH BROADWAY • BILLINGS, MT 59107-0916 • PHONE (406)252-6325
FAX (406)252-6069 • 1-800-735-4489

LABORATORY REPORT

TO: City of Missoula
ADDRESS: Wastewater Treatment Plant
435 Ryman Street
Missoula, MT 59802

LAB NO.: 91-44921
DATE: 12/16/91 rh

WATER ANALYSIS

Final Effluent
Sampled 11/12-13/91 @ 2130-2130
Submitted 11/15/91

Total Metals	mg/l(ppm)
Arsenic	<0.005
Cadmium	<0.001
Chromium	<0.02
Copper	0.02
Lead	<0.01
Mercury	<0.001
Nickel	<0.03
Silver	<0.005
Zinc	0.10

Figure 16

Fecal Coliform Bacteria in MWWTP Effluent
(MWWTP, 1998)

DATE	COLIFORMS colonies/ 100 ml
6/3/96	
6/4/96	3000
6/5/96	3100
6/6/96	2525
6/9/96	
6/10/96	4950
6/11/96	1025
6/12/96	613
6/13/96	
6/16/96	
6/17/96	1975
6/18/96	6250
6/19/96	1075
6/20/96	
6/23/96	
6/24/96	
6/25/96	500
6/26/96	225
6/27/96	1370
6/30/96	
7/1/96	2350
7/2/96	17500
7/3/96	18700
7/4/96	
7/7/96	
7/8/96	
7/9/96	3325
7/10/96	2050
7/11/96	100
7/14/96	
7/15/96	
7/16/96	100
7/17/96	20
7/18/96	80
7/21/96	
7/22/96	15
7/23/96	31.2
7/24/96	159
7/25/96	
7/28/96	
7/29/96	50
7/30/96	5620
7/31/96	66
8/1/96	
8/4/96	
8/5/96	20
8/6/96	350
8/7/96	21000
8/8/96	
8/11/96	
8/12/96	80
8/13/96	70
8/14/96	886
8/15/96	
8/18/96	
8/19/96	58
8/20/96	92
8/21/96	100
8/22/96	
8/26/96	1650
8/27/96	1800
8/28/96	20
8/29/96	
9/1/96	
9/2/96	1200
9/3/96	465
9/4/96	4575
9/5/96	
9/8/96	
9/9/96	500
9/10/96	200
9/11/96	50
9/12/96	
9/15/96	
9/16/96	250
9/17/96	40
9/18/96	50
9/19/96	
9/22/96	
9/23/96	
9/24/96	223
9/25/96	3360
9/26/96	300
9/29/96	
9/30/96	
6/2/97	15
6/3/97	65
6/4/97	12.5
6/5/97	
6/6/97	
6/9/97	
6/10/97	
6/11/97	6750
6/12/97	10
6/13/97	20
6/16/97	70
6/17/97	170
6/18/97	30
6/19/97	
6/20/97	
6/23/97	220
6/24/97	30
6/25/97	24
6/26/97	
6/27/97	
6/30/97	31800
7/1/97	4250
7/2/97	1030
7/3/97	
7/4/97	
7/7/97	200
7/8/97	295
7/9/97	4330
7/10/97	
7/11/97	
7/14/97	222
7/15/97	4000
7/16/97	200
6/11/98	10100
6/12/98	
6/15/98	
6/16/98	800
6/17/98	950
6/18/98	610
6/19/98	
6/22/98	3500
6/23/98	20600
6/24/98	1060
6/25/98	
6/26/98	
6/29/98	
6/30/98	450
7/1/98	5100
7/2/98	1625
7/3/98	
7/6/98	710
7/7/98	250
7/8/98	1660
7/9/98	
7/10/98	
7/13/98	
7/14/98	550
7/15/98	1850
7/16/98	150
7/17/98	
7/20/98	
7/21/98	7300
7/22/98	5300
7/23/98	300
7/24/98	
7/27/98	
7/28/98	
7/29/98	150
7/30/98	380
7/31/98	3400
8/3/98	
8/4/98	300
8/5/98	2950
8/6/98	200
8/7/98	
8/10/98	300
8/11/98	200
8/12/98	35625
8/13/98	
8/14/98	
8/17/98	
8/18/98	1550
8/19/98	205
8/20/98	450
8/21/98	
8/24/98	
8/25/98	200
8/26/98	500
8/27/98	1790
8/28/98	
8/31/98	
9/1/98	500
9/2/98	18500
9/3/98	
9/4/98	
9/7/98	400
9/8/98	2375
9/9/98	8400
9/10/98	
9/11/98	
9/14/98	750
9/15/98	2375
9/16/98	8400
9/17/98	
9/18/98	
9/21/98	
9/22/98	15900
9/23/98	90
9/24/98	10400
9/25/98	
9/28/98	
9/29/98	
9/30/98	