Appendix D: Technical Appendix on Use of Piscicides

This Technical Appendix presents a summary of the origin, uses, and consequences of piscicides (chemical substances used to eliminate undesirable fish species from a selected water body) with a focus on the piscicide rotenone. This appendix also provides a detailed description of past and present uses of these piscicides specific to Montana, and of procedures and protocols for rotenone application within the state. Much of the information in this appendix, unless otherwise stated, is taken from Skaar (2001). Skaar's work, in turn, relies heavily on the following review documents: *A Review of the Literature on the Use of Rotenone in Fisheries* (R.A. Schnick 1974; Fish Control Laboratory, U.S. Fish and Wildlife Service); *Rotenone Use for Fisheries Management, Final Programmatic Environmental Impact Report (Subsequent)* (California Department Fish and Game, 1994); and *Rotenone and Trout Stocking. A literature review with special reference to Washington Department of Game's Lake Rehabilitation Program* (Bradbury 1986). Procedural details specific to Montana are supplied by Grant Grisak, Fisheries Biologist for Montana Fish, Wildlife and Parks (MFWP) (Grisak 2002). Please see the references section of this Technical Appendix.

Historic Use of Piscicides to Manage Fisheries

Piscicides are chemical substances introduced into lakes or streams to kill unwanted fish. Fish managers in North America began using rotenone to manage fish populations in the 1930s [1:1]. It was often used where exotic (non-native) fish had been introduced and had subsequently affected native populations of fish. According to the American Fisheries Society's *Rotenone Use in Fisheries Management: Administrative and Technical Guidelines Manual* (Manual) (Finlayson, et al. 2000; Finlayson, et al. 2000), by 1949, " . . . 34 states and several Canadian provinces were using rotenone routinely for management of fish populations" (Solman 1950; Lennon, et al. 1970). Management may include elimination of fish from a given body of water or sampling of fish populations. Rotenone has also been used as a natural insecticide for agricultural purposes. It has even been used in humans to control intestinal worms (Haley 1978).

Today, according to the American Fisheries Society Manual, rotenone is used in fisheries management for several purposes:

1. To support recreational fisheries by controlling undesirable fish,
2. To eradicate exotic fish,
3. To eradicate competing fish species in rearing facilities or ponds,
4. To quantify populations of aquatic organisms,
5. To treat drainages before initial reservoir impoundment
6. To eradicate fish to control disease, and
7. To restore threatened or endangered species (Finlayson, et al. 2000).

In addition to use of chemicals, a variety of methods may be used to manage fisheries. These include the modification of angling regulations to protect some species or to increase harvest of others; physical removal methods such as trapping or electro-shocking fish; the introduction of predators, explosives, physical methods of manipulating flow or introducing physical barriers in a given stream; and complete dewatering of a body of water (Finlayson, et al. 2000). (For more information on the benefits and drawbacks of each of these fish management methods, see the AFS website listed under *References*.)

However, when complete eradication of a species or of all fish in a body of water is the objective, the only viable management solution is chemical use (by introducing one of two chemicals: either rotenone or antimycin) or dewatering. Dewatering can cost less initially, but it can be more environmentally disruptive to an area (Finlayson, et al. 2000). Rotenone is covered extensively here, as it is the chemical most often used; antimycin is covered briefly at the end of this discussion.

Rotenone

Rotenone is a chemical used for several purposes, including a pesticide for gardening and the removal of undesirable fish in bodies of water. This chemical compound, extracted from the roots of certain species of the bean family, has been used down the centuries to capture fish (Finlayson, et al. 2000). Introduced in powdered or liquid form (with a dispersant, usually a petroleum-based solvent) into water where fish live, rotenone interferes with cellular respiration in gill-breathing animals. Both fish and aquatic insects are highly susceptible to rotenone (Skaar 2001). However, mammals in general are not; mammals neutralize rotenone by enzymatic action in their stomach and intestines (AFS 2000).

Rotenone breaks down naturally and rapidly in water and with exposure to UV light. However, the process may be hastened with the addition of a neutralizer (usually chlorine or potassium permanganate[3]) to the lake water after a short period of time (Finlayson, et al. 2000; Skaar 2001). The toxic effects of rotenone, on some fish, can be reversed, depending on how much is absorbed (Grisak 2002). “Inert” (i.e., non-lethal) ingredients may be added rotenone to enhance its ability to dissolve and disperse throughout a given body of water (Skaar 2001). In a study conducted by the State of California (CDFG, 1994, cited in Skaar 2001), researchers found the following inert ingredients: trichloroethylene (TCE), naphthalene, 2-methylnaphthalene, and xylene (see Regulatory Status, below). Follow-up visit(s) to the lake are required to determine rate and completeness of rotenone degradation via bioassay. If the desired object is to introduce or re-establish a native species of fish in those waters, appropriate broodstock may then later be seeded in the lake or river.

Rotenone Effects

Rotenone is toxic to gill-breathing organisms and is most commonly used on fish. Salmonids are the most sensitive to treatment; salmonid eggs are more resistant than fry or fingerlings (Skaar 2001: 4). Stream-dwelling insects are far more sensitive to rotenone than those in lakes (Skaar 2001:4). Adult frogs and other amphibians would not be seriously affected, but tadpoles and juvenile salamanders would probably be killed as a result of application (Sport Fish Restoration). The effect on amphibians is largely dependent on the time of year rotenone is applied. Fall applications greatly reduce and perhaps eliminate impacts on amphibians of all age classes because these species are in the adult stage.

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[3] Use of potassium permanganate ($KMnO_4$) must be carefully planned because “it is itself toxic to fish in relatively low concentrations” (Skaar 2001:2).

Swine may also be sensitive to rotenone (Clemson University Extension). Rotenone is slightly toxic to wildfowl (EXTOXNET 1996). In laboratory tests on rats and dogs that were fed forms of rotenone as part of their diet for periods of six months to two years, researchers observed effects such as diarrhea, decreased food consumption, and weight loss. In other laboratory tests, rotenone was not found to affect reproductive functions (Skaar 2001:4-5). CDFG studies of risk for terrestrial animals found that a 10-kilogram (kg) dog would have to drink 7,915 gallons of lake water within 24 hours, or eat 300,000 kg of rotenone-tainted fish to receive a lethal dose (cited in Skaar 2001:5). Similar results were determined for birds: " . . . environmental levels of rotenone are at least 1,000 to 10,000-fold less than that required for lethality" (Skaar 2001:5).

Because dead fish will result from a rotenone treatment, there would be a temporary overabundance of food for predators following rotenone treatment; this would be followed by a temporary reduction in food supplies until fish are restored (Finlayson, et al. 2004). The rotenone manual (Finlayson, et al. 2000) notes, "There is no indication that this temporary reduction results in any significant impacts to most bird or mammal populations because most animals can utilize other water bodies and sources for food" (Finlayson, et al. 2000:194). If this shortage were to occur during mating season, some birds could be affected unless steps were taken to time rotenone application outside nesting and fledging season (Finlayson, et al. 2000:194).

Several hazard assessments for human health have also been conducted. The lowest level estimated for toxicity would require a 60-kg person to drink, at one time, 180,000 liters of water containing 100ug/L rotenone; or to eat 180 kg of rotenone-killed fish at one sitting. Human ingestion at these levels could be lethal (Gleason et al., 1969, cited in Skaar 2001:5).

One study, in which rats were injected with rotenone for a period of weeks, reported finding lesions characteristic of Parkinson's disease (Bertarbet, et al. 2000). However, the results have been challenged on the basis of methodology: The continuous intravenous injection method used leads to "continuously high levels of the chemical in the blood," and dimethyl sulfoxide (DMSO) was used to enhance tissue penetration. (Normal routes of exposure actually slow introduction of chemicals into the bloodstream.) Similar studies (Skaar 2001 cites Marking 1988) have found no Parkinson-like results. Finally, intramuscular injection into the body is not a normal way (i.e., ingestion) of assimilating the compound.

Skaar (2001) notes that the National Academy of Sciences established (in 1983) a Suggested No-Adverse Response Level of rotenone in drinking water of 14 ug/L, assuming that a 70-kg person drinks 2 liters of water per day for a lifetime. In 1997, the U.S. EPA established a "reference dose"[4] of 0.004mg/ks/d, based on a No Observable Adverse Effect Level in rats of 0.38/mg/k/d. Skaar (2001) notes that freshly treated lakes will have a rotenone level much higher (100 ug/L); however, he notes that since the rotenone will "probably dissipate totally within a month or two, it doesn't seem possible for chronic effects to ever develop from drinking from a rotenone-treated lake" (Skaar 2001:6).

[4] A "reference dose" is an estimate of "a daily exposure to the human population (including sensitive sub-groups) that is likely to be without an appreciable risk of deleterious effects during a lifetime. (EPA 1997, cited in Skaar 2001). The EPA used an uncertainty factor of 100 to account for extrapolation between species and differences in sensitivity within the human population (Skaar 2001:6).

Extensive research has demonstrated that rotenone does not cause birth defects [(Hazelton 1982)], reproductive dysfunction (Spencer & Sing 1982), gene mutations (Biotech 1981; Goethem, Barnhart, & Fotopoulos 1981; NAS 1983) or cancer (USEPA 1981; Tisdel 1985). The USEPA (USEPA 1981; 1989) ". . . has concluded that the use of rotenone for fish control does not present a risk of unreasonable adverse effects to humans and the environment" (Finlayson, et al. 2004). In relation to air quality, the rotenone manual (Finlayson, et al. 2000) further notes that "No public health effects from rotenone use as a piscicide have been reported."(Finlayson, et al. 2000). No waiting period is specified for swimming in rotenone-treated water.

Skaar (2001) cites Bradbury (1986) in noting that studies show that water temperature, dissolved oxygen, pH, alkalinity, and carbon dioxide are not affected by water treatment with rotenone. Minor temporary changes in taste and odor can be detected. No well-designed studies have ever shown detectable levels of any of the chemicals involved, post-treatment (Skaar 2001:3).

Some temporary recreational and aesthetic impacts may be expected in a body of water where dead fish appear in some quantities. This may be mitigated by removing the fish from the shoreline following the procedure. A treated body of water would have no fish for angling opportunities until after it is restocked. Guides or outfitters using these waters for commercial enterprise would have to find other nearby water resources until a fishery was re-established.

Use of rotenone has raised controversy in some places, particularly where sufficient public involvement or education has not taken place. According to members of the AFS Fish Management Chemicals Subcommittee Task Force on Fishery Chemicals, controversy springs from three main sources: "(1) persons who oppose changes to a perceived natural situation or oppose the use and development of fish monocultures, (2) persons who are alarmed by the perception of widespread application of chemicals that might be dangerous to people and the environment, and (3) persons who oppose the killing fish by any means" (AFS 2000).

Rotenone and National Environmental Policy Act (NEPA) Coverage

California, Washington, and Michigan, among other states, have prepared programmatic environmental studies of rotenone use in fisheries management (WDG 1986; MDNR 1990; WDW 1992; CDFB 1994). Site-specific environmental studies are conducted for each individual rotenone treatment in California (Finlayson, et al. 2000:38-39). Environmental assessments are conducted and public notices issued for each chemical treatment project on public land in Montana (Skaar 2001:8).

Rotenone Application in the Flathead Valley

History and Authority

Between 1948 and 2001, MFWP administered a total of 74 rotenone applications on 63 lakes in the Flathead basin. Between 1948 and 1999, seven of these lakes (11 percent) have required multiple treatments. Reasons for multiple treatments include lack of success in eliminating the non-native species, inability to remove the source of unwanted fish, or illegal introduction of non-natives (by others) following a treatment. The target species from these seven lakes have been pumpkinseed sunfish, northern pikeminnow, black bullhead, red-side shiner, yellow perch, largemouth bass, coarse scale sucker, longnose sucker, finescale sucker, peamouth, eastern brook trout and, rainbow trout. The average length of time between repeat treatments has been 19 years; it ranges from 8 to

36 years. The number of lakes treated with rotenone in the Flathead basin represents only 12 percent of the 505 lakes the department considers as managed fisheries.

MFWP is authorized by law to manage (MCA 87-1-201) and/or restore (MCA 87-1-207) the fisheries resources of Montana, specifically so as to keep any species from being listed as a Federally Endangered Species. Furthermore, it is within the state's purview to stock fish into waters designated as sustainable fisheries, or those necessary to achieve the management goals identified under the above statutes to keep a species from being listed as endangered.

Tom-Tom and Whale, two high mountain lakes located in the Flathead basin, were treated in 2000 to remove hybrid trout. Both lakes were replanted (in July and September 2001, respectively) and the re-established populations have since naturally spawned and are providing sport angling. The goal of the South Fork Flathead Watershed/Westslope Cutthroat Trout Conservation Program is to remove the non-native trout that are moving out of the lakes and hybridizing with genetically pure native westslope cutthroat trout. The proposed treatment using rotenone would eliminate this threat. The lakes would then be restocked with genetically pure westslope cutthroat trout.

Regulatory Status

The State of Montana has Human Health water standards and the EPA has water quality criteria for chronic effects of some of these compounds. The EPA has no drinking water standards for rotenone. According to Skaar (2001), use of rotenone in Montana has been governed for many years by the "Surface Water Quality Standards and Procedures" rules (ARM 17.30.637 (3)(B)), which state:

"If the department [DEQ] approves the location, timing, and methods of game fish population restoration authorized by the Department of Fish, Wildlife and Parks, restoration activities causing violations of surface water quality standards may be exempt from the standards."

This exemption from water quality standards was officially adopted into statute in 1993, with the passage of section 75-5-308 of the Montana Water Quality Act. This statute states:

> "The department [DEQ] may authorize short-term exemptions from the water quality standards or short-term use that exceeds the water quality standards for the purpose of allowing construction, emergency environmental remediation, pesticide application, elimination of undesirable and nonnative aquatic species, and treatment of water for the protection of public health. The authorization must include conditions that minimize to the extent possible the magnitude of any standard violation and the length of time during which any standard violation may occur. The authorization conditions must maximize the protection of state waters by ensuring the maintenance of beneficial uses after the term of the authorization. Authorizations issued under this section may include conditions that require water quality or quantity monitoring and reporting. In the performance of its responsibilities under this section, the department may negotiate operating agreements with other departments of state government that are intended to minimize duplication in review of activities eligible for authorization under this section."

These procedures have been followed in the 1990s. In addition, the State has prepared Environmental Assessments and issued public notices for each project that involves the use of rotenone on public lands.

Rotenone Procedures and Policies

Timing of Rotenone Treatments

Rotenone would be applied in the fall. During this time of year, water levels are generally low, recreational use of the lake is reduced, and most lakes' summer thermal stratification has ended (allowing rotenone to circulate throughout the water column more quickly).

Rotenone Application Procedures

Powdered rotenone is occasionally used in Montana to rid waters of unwanted fish. An electric cement mixer is commonly used on the shoreline to mix the dry form with lake water creating a slurry. The mixture is then applied using standard boat methods described below. All people involved in mixing and applying powdered rotenone must use respirators and eye protection to keep powdered materials from entering the body. For these reasons, liquid rather than powdered rotenone would be used for this proposed project.

Liquid rotenone (the method selected for this proposed project) may be applied to a lake in two ways. Most commonly, the liquid is siphoned out of a barrel with a venturi suction mechanism mounted to the lower unit of an outboard motor directly in front of the propeller. The propeller can then mix the rotenone with water and facilitate distribution. In deeper lakes, a weighted garden hose of appropriate length attached to a pump may be used to distribute the chemical in deeper waters. A CO_2 pressurized barrel and hose may also be used to distribute at deeper depths. Application during the fall of the year takes advantage of the limnetic turn-over in which water density and temperature are consistent throughout the lake; this factor allows for better mixing of rotenone with lake water.

The second method is typically used in small shallow lakes (<15 feet deep): an auxiliary pump is used to mix lake water with rotenone before spraying the mixture over the lake surface while the boat transports the bulk rotenone and applicator.

A typical application requires six people: one boat operator, two drip station installers; one detox person; one spot sprayer; and one person to load barrels of rotenone, triple rinse empty barrels, and to load/unload cargo nets for the helicopter pilot. Two additional people are necessary for each additional boat.

The boat crew first dispenses the rotenone around the shoreline of the lake, continuing the application in concentric rings toward the center until the upper stratum is treated. If necessary, the boat then dispenses rotenone in deeper water, using pumps, and a weighted garden hose.

Simultaneously, other crew members set up drip stations at designated locations, and crews walk the perimeter of the lake to spot spray other water sources. Drip stations for rotenone are used to counter attempts by fish to avoid the rotenone application (they can smell the petroleum emulsifier that is added to make it more soluble in water) by seeking out fresh-water inputs to the lake. For this reason, it is often necessary to install drip stations at those sources around the lake. Drip rates are calculated to ensure that the fresh water sources are discharging (into the lake) lethal doses of rotenone during the treatment period. This step keeps fish from recovering from an initial rotenone exposure.

Drip stations dispense rotenone at a prescribed rate. Crew members often walk the lake perimeters to see whether fish are seeking fresh-water inputs that were not previously identified (i.e., spring inputs versus surface water). A backpack sprayer may be used to spot-spray these water sources. Because the application of rotenone causes lake water to temporarily turn milky-white, it is easy to identify most fresh-water sources, which appear as clear plumes of water.

In streams, known quantities of rotenone are dispersed through drip stations based on the calculated concentration needed to meet the fish removal objectives. Drip stations are typically run for 8 to 12 hours depending on the objectives. Caged fish are used to determine the lethality of stream water, when the desired kill has occurred, and when water is safe for restocking. Drip stations and caged fish stations are monitored continually during a treatment.

Safety Measures

At least one applicator licensed by the Montana Department of Agriculture must be on site to supervise or administer the project. Non-licensed applicators may assist with the project under the direct technical supervision of the licensed applicator. The project supervisor must be well versed in the state regulatory requirements regarding safe and legal use of the rotenone product and applicator safety. All personnel involved with the rotenone application must receive safety training specific to the formulated rotenone product to be used.

At a minimum, specific safety training must include information on the following: (1) properly reading and understanding the product label; (2) the acute and chronic applicator exposure hazards; (3) routes and symptoms of pesticide overexposure; (4) how to obtain emergency medical care; (5) decontamination procedures; (6) how to use the required safety equipment; (7) safety requirements and proper procedures for pesticide handling, transportation, storage and disposal. The Training Records must be maintained in accordance with federal and state regulatory requirements.

When applying liquid rotenone, personnel are required to wear protective clothing, including chest waders, waterproof jacket (rain jacket), and rubber gloves. If mixing powdered rotenone, personnel are required to wear respiration filter masks and eye protection to keep from inhaling or ingesting any powdered material.[5] Pumping any rotenone mixture for a surface application requires that personnel wear respiration filter masks and eye protection to avoid inhaling or ingesting aerosol droplets.

Before application, MFWP must apply for and secure a 308 permit from the Montana Department of Environmental Quality. This permit allows for short-term exemptions for water quality issues.

Rotenone Detoxification

Background

Rotenone breaks down rapidly in soil and water (EXTOXNET 1996) as it is exposed to light, heat, oxygen, and alkalinity (Skaar 2001:2). Other factors that contribute to

[5] The plan is to use liquid rotenone for this project.

degradation include the presence of organic debris, turbidity, lake morphology, dilution by freshwater, and the dosage used (Skaar 2001:2). Degradation is slower under conditions of cold temperature or higher elevation (Skaar 2001:2). Rotenone has a half-life of between three and five days. Because it binds readily to sediments, it does not readily leach from soil, nor is it expected to be a groundwater pollutant. Most lakes completely detoxify within five weeks of treatment.[6] Rotenone breaks down ultimately into carbon dioxide and water (Sousa, et al. 1991).

The "inert" ingredients commonly associated with formulations of rotenone are highly volatile and water soluble (Skaar 2001:3). Skaar notes that "These constituents tend to dissipate to non-detectable levels in less than 14 days in treated impoundments with water temperatures above 50°. None of the constituents has been found in groundwater aquifers following treatment" (Skaar 2001:4). TCE, a known carcinogen, "dissipates quickly by volatilization, less so by oxidation, and very slowly by hydrolysis" (Skaar 2001:3). Results from CDFG (1994) show that it can be found in impoundments three weeks after treatment; the study notes that in Lake Davis, in California, TCE concentrations fell below detection limits only after 37 days post-treatment (cited in Skaar 2001:3). Piperonyl butoxide (the other active ingredient in synergized formulations) remained above the detection limit of 2 ppb in Lake Davis from treatment (October 15) to the following June (cited in Skaar 2001:3).

Montana Procedures

Rotenone will degrade naturally in the treated lake. However, in lakes with stream outlets, outflow must be non-existent or detoxified so as not to affect downstream non-target fish. Dilution of rotenone-treated water by downstream freshwater inputs may reduce the concentration to sub-lethal levels. When this is not possible, an oxidizing agent—usually potassium permanganate—is dripped into the outlet stream to detoxify the rotenone before it can affect non-target organisms downstream. Finlayson et al. (2000) provide detailed guidelines for detoxification with potassium permanganate.

Recent bioassays conducted on westslope cutthroat trout in Montana indicate that potassium permanganate applied in glass aquaria at 1.5 ppm and greater can achieve 100 percent mortality after 16 to 24 hours of exposure (Grisak et al. 2002). Assays including rotenone demonstrated that its toxicity to fish was greatly reduced in the presence of potassium permanganate. Subtle adjustments in concentration of each compound would be made for each lake and stream treatment, and would take into account other factors that influence efficacy of potassium permanganate--like plankton, and interface with stream and lake bottom, water chemistry, etc. (Engstrom-Heg 1971; 1976).

It is common for many lakes in the Flathead watershed to experience low or no outflow in the fall. For this project, lakes with no outflow may be scheduled for treatment first so that no detoxification would be necessary.

The crew detoxifies the lake by one of several methods.

<u>Natural breakdown.</u> The most common method is to allow natural breakdown to occur. A variety of factors influence natural breakdown, including water chemistry, water temperature, and sunlight intensity.

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[6] Skaar notes that in the State of Washington, rotenone-treated lakes remained toxic to fish for a "mean length time of 4.55 – 4.8 weeks." He also notes that most of these lakes "had been poisoned in the fall and had mean surface water temperatures of 57-58° and pH of 7.8 – 8.3 (Bradbury 1986, cited in Skaar 2001).

Basic dilution. This method depends on fresh-water inputs to dilute the concentration of rotenone to levels sublethal to the target species.

Application of binding agent. Other methods rely on the application of a binding agent such as potassium permanganate ($KMnO_4$). This dry crystalline substance is mixed with lake water to produce a concentration of liquid sufficient to detoxify the concentration of rotenone applied. It may be applied to the effluent stream of a lake or reservoir to mix with rotenone-laced water, detoxifying the rotenone. Detoxification is accomplished within about 20-30 minutes of mixing. The potassium permanganate is generally applied using a drip station as described.

> A treatment of potassium permanganate may also be administered by boat to reduce rotenone concentration to a level sublethal to the fish species downstream of the lake. This eliminates the need to staff drip stations at the outlet of the lake for long periods of time.

Simple dilution of effluent stream water may be accomplished by inflow of fresh stream water from downstream inputs.

For each water body treated, the certified applicator submits a Montana Department of Agriculture Record of Application Report that describes, among other things, the type and amount of pesticide applied, the area treated, application rate, equipment used, possibility of a complete kill, water conditions at the time of treatment, and detoxification measures, if any.

Potassium Permanganate

The following information on potassium was taken from the manufacturer's website and contains basic information about the chemical and its uses.

Potassium permanganate is one of the most widely used inorganic chemicals for the treatment of municipal drinking water and wastewater. Hundreds of drinking water treatment plants, large and small, use this versatile oxidant to improve taste and odors; to oxidize iron, manganese, and arsenic; to treat for and control zebra mussels and biofilm in raw water intake lines; to remove color; and to provide an alternative pre-oxidant to chlorine in a trihalomethane (THM) control program. Potassium permanganate is used to treat ground water as well as surface supplies.

In municipal wastewater systems, potassium permanganate is used cost effectively to control odors in collection systems, in the treatment process, and in the mechanical dewatering operations. It is especially effective in oxidizing sulfides and mercaptans, the worst odors generated during the collection and treatment of municipal wastewater.

Municipal Drinking Water Treatment

In the American Waterworks Association's (AWWA) Water Industry Data Base (WIDB), potassium permanganate is listed as the second most widely used chemical for predisinfection and oxidation by treatment plants processing surface water. According to the data base, over 32.9 percent of the surface water plants use potassium permanganate, second only to chlorine, for disinfection and oxidation. In groundwater plants, over 22.6 percent of the plants practicing iron and manganese removal are using potassium permanganate.

The AWWA Research Foundation (AWWARF) conducted a survey of treatment plants and their practices for controlling tastes and odors. Next to activated carbon, potassium permanganate was the most widely used taste and odor control process. Over 48 percent of the plants in the survey listed permanganate usage with an 86 percent satisfaction factor.

Wastewater Treatment

Since its introduction in the early 1980s, the use of potassium permanganate for wastewater treatment has grown to become one of the largest U.S. applications of this versatile oxidant. The major use is for the oxidation of hydrogen sulfide, the "rotten egg" odor caused by the reduction of sulfur compounds normally present in wastewater. In test after test, $KMnO_4$ has been proven to be the fastest working oxidant for this application. Most other sewage odors can also be controlled using potassium permanganate.

The $KMnO_4$ application is especially effective in mechanical biosolids dewatering where toxic sulfides pose a threat to the health of wastewater plant operators as well as to the environment. Control of sulfides also reduces corrosion. Case histories and technical support literature are available.

Municipal Drinking Water Applications

Potassium Permanganate is being used successfully by utilities to remove iron, manganese, and hydrogen sulfide from both groundwater and surface water. In groundwater applications, the permanganate is normally applied directly ahead of greensand filtration. In surface water treatment plants, permanganate is applied as far ahead of the rapid mix as plant design allows, preferably at the raw water intake. Factors that affect oxidation and coagulation include pH, hardness, alkalinity, TOC, and time between permanganate addition and the addition of coagulants.

Potassium permanganate is being used by surface water utilities to successfully remove the cucumber, fishy, septic, and other odors caused by blue-green algae. In combination with activated carbon, utilities report that permanganate is cost effective in controlling musty, earthy odors. The oxidant should be applied before the rapid mix ahead of activated carbon. Potassium permanganate has been approved by U.S. EPA as an alternative oxidant to chlorine in a THM control program. Arsenic (+3) is readily oxidized to Arsenic (+5) by permanganate. The oxidized arsenic is easily adsorbed by alum, iron salts, or manganese treated greensand. Utilities report that potassium permanganate applied at the raw water intake successfully removes zebra mussel infestations and prevents the settling of veligers in pipelines. Other pipeline biofilms are also controlled.

The major application of potassium permanganate in municipal drinking water plants using surface water, is for the control of compounds causing tastes and odors. Surveys have shown that most off-flavors in drinking water are caused by metabolizing blue-green algae. Potassium permanganate treatment, either alone or in combination with other treatment technologies, is effective in controlling these algae generated odors.

According to the work presented at the Water Quality Technology Conference (WQTC), potassium permanganate is more effective at controlling “cucumber” and “grassy” odors than either chlorine or chlorine dioxide.

Potassium permanganate can be combined with powdered activated carbon (PAC) to achieve odor control of musty and earthy odors caused by MIB and Geosmin.

Recycled decant and backwash water can cause taste and odor problems. Permanganate treatment was proven to be more economical and effective than ozone for the control of these tastes and odors.

Trihalomethanes (THMs) and other chlorinated organics are formed when "free" chlorine or other halogens react with organic precursor chemicals in the raw water. By delaying the application of chlorine and applying potassium permanganate to the raw water as a substitute oxidant, and by practicing good coagulation, levels of THMs and other chloro-derivatives can be reduced to meet Safe Drinking Water Act (SDWA) standards. Potassium permanganate is listed by U.S. EPA in the Federal Register as one of the technologies that can be used in a THM control program.

Manganese and iron can be problems in both surface water and groundwater plants. Potassium permanganate effectively oxidizes both of these metals quickly and efficiently. In groundwater plants, permanganate is normally combined with manganese treated greensand filtration.

Arsenic standards may be reduced by changes in the SDWA. Potassium permanganate has been proven an effective oxidant to convert arsenic so that it can be adsorbed in subsequent treatment unit processes.

Zebra mussel control is essential in many surface water treatment plants. Potassium permanganate has case history articles available from utilities who claim effective control using potassium permanganate.

Municipal Wastewater Applications

Potassium permanganate rapidly oxidizes sulfides and other sewage odors in collection systems, in plant treatment processes, and in mechanical biosolids dewatering operations. Corrosion control, improved plant performance, and polymer savings are some of the benefits achieved. The addition of permanganate to Return Activated Sludge has resulted in the reduction of odors from aeration tanks in a conventional activated sludge wastewater treatment plant without any change occurring to the microbiology of the system.

Hydrogen sulfide is one the deadly gases that can be formed in the collection and treatment of municipal wastewater. Other organic sulfur compounds include thiols, mercaptans, and disulfides. These compounds and other nitrogen containing compounds can produce odors described as "skunk, rotten cabbage, rotten eggs, fishy, ammonia, and decaying flesh." The lack of oxygen in the collection system force mains and the active anaerobic bacteria present in a sewage system can chemically reduce sulfates and other chemicals resulting in the production of odorous compounds. These odors become prevalent in lift stations, force main discharges, and at the headworks of treatment plants. Potassium permanganate can be applied to collection systems ahead of the odor source to control most of these odors.

In-plant odors can occur at the headworks, in the primary and secondary clarifiers, in the activated sludge basins, in the fixed film reactors, and during bisolids handling and disposal. Potassium permanganate can be applied economically and effectively to oxidize the odorous compounds.

Additional Information

Potassium permanganate is normally fed early in the drinking water treatment process to allow for as much reaction time as possible before other treatment chemicals are added.

This allows for the permanganate to be reduced to form maganese dioxide, which is then coagulated and flocculated out of the system. Only systems employing filtration should use potassium permanganate because of the need to remove the by-product manganese dioxide from the water.

Industries have developed analytical methods to measure residual permanganate in water to provide analytical control tools. Potassium permanganate can be measured in the presence of residual by-product MnO_2 and chlorine.

In wastewater treatment systems, potassium permanganate should be applied as close to the odor source as possible to provide the best and fastest control. In dewatering operations, the potassium permanganate is applied directly ahead of the sludge pumps or into the sludge conditioning tanks.

Information obtained from Carus website (www.carsuchem.com). Product line is CAIROX®

Cleanup

The day after the proposed treatment is complete, the site is cleaned up. Drip stations are cleaned and removed. Other equipment and materials are removed from the site. A sub-sample of the dead is collected for measuring, weighing, scale sampling, etc. The fish that wash up on the shoreline during the project and immediately afterwards, are taken to deeper water, their air bladders punctured, then sunk. This step provides two benefits: first, nutrients from the dead fish are valuable in stimulating the primary production of the lake, which facilitates plankton blooms that serve to feed fish that are restocked in to the lake following treatment. Second, clearing dead fish from these areas improves aesthetics.

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