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**EVALUATION OF SURFACE WATER TREATMENT
AND DISCHARGE OPTIONS FOR THE
WELDON SPRING SITE REMEDIAL ACTION PROJECT**

by

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INTRODUCTION

The U.S. Department of Energy (DOE), under its Environmental Restoration and Waste Management Program, is responsible for conducting response actions at the Weldon Spring site in St. Charles County, Missouri. The site consists of two noncontiguous areas: (1) the chemical plant area, which includes four raffinate pits and two small ponds, and (2) a 3.6-ha (9-acre) quarry located about 6.4 km (4 mi) southwest of the chemical plant area. Both of these areas became chemically and radioactively contaminated as a result of processing and disposal activities that took place from the 1940s through 1960s. The Weldon Spring site, located about 48 km (30 mi) west of St. Louis, is listed on the National Priorities List of the U.S. Environmental Protection Agency.

Nitroaromatic explosives were processed by the Army at the chemical plant area during the 1940s, and radioactive materials were processed by DOE's predecessor agency (the Atomic Energy Commission) during the 1950s and 1960s. Various wastes were disposed of in the quarry from 1942 to 1969, including contaminated soil and sediment, rubble, metal debris, and equipment. During the 1950s and 1960s, waste slurries from uranium and thorium processing at the chemical plant were piped to four raffinate pits constructed from existing clay at the chemical plant area. The solids settled to the bottom of the pits, and the supernatant liquids were decanted to the plant process sewer that drained off-site through the Southeast Drainage, a natural channel that extends through a state wildlife area to the Missouri River (Figure 1).

Overall remediation of the Weldon Spring site is being addressed through the Weldon Spring Site Remedial Action Project, and it consists of several components. One component is the management of radioactively and chemically contaminated surface water impoundments at the chemical plant area — i.e., the four raffinate pits, Frog Pond, and Ash Pond (Figure 1) — which was addressed under a separate action and documented in an engineering evaluation/cost analysis (EE/CA) report (MacDonell et al 1990). The raffinate pits contain about 150,000 m³ (200,000 yd³) of contaminated solids, which include neutralized raffinate sludge and slag resulting from past uranium refining and other operations at the chemical plant. One pit also contains wastes from the processing of thorium-containing materials and drums and rubble from a partial decontamination of the chemical plant in 1967. The solids in the raffinate pits are covered with water, the amount of which depends on climatic conditions and averages about 216,000 m³ (57,000,000 gal).

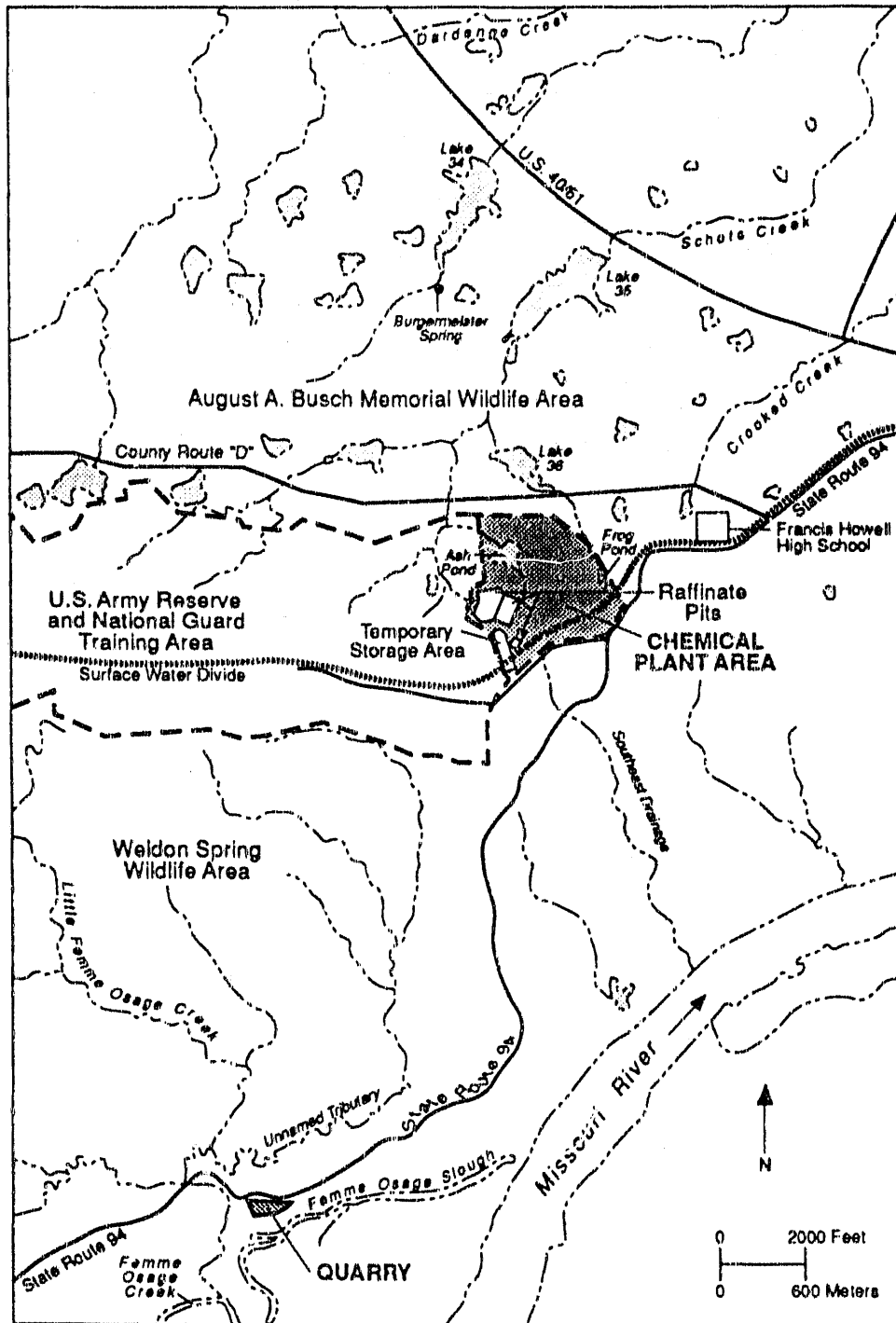


FIGURE 1 Surface Features near the Weldon Spring Site
 (Source: Modified from MacDonell et al. 1990)

Frog Pond, located near the eastern boundary of the chemical plant area, was excavated from an existing drainage for use as a settling basin during the operational period of the chemical plant. The pond currently receives water from storm drains at the chemical plant and from surface runoff in the northeastern portion of the site. Frog Pond contains about 2,000 m³ (500,000 gal) of water, depending on climatic conditions.

Ash Pond is located in a topographic low near the northern boundary of the chemical plant area and previously received slurried ash discharged from the coal-fired power plant on-site. In 1989, a dike and drainage system was constructed at Ash Pond to mitigate contaminant releases off-site by diverting surface water runoff away from an adjacent dump area. Prior to construction of the diversion system, standing water was present intermittently at various levels, depending on climatic conditions. The volume of surface water in Ash Pond is conservatively assumed to average 6,800 m³ (1,800,000 gal).

The alternative selected for the impounded waters as a result of the EE/CA process was to treat the waters in a facility constructed at the chemical plant area and release the treated water to the Missouri River in compliance with a permit issued to DOE by the Missouri Department of Natural Resources. This paper describes the evaluation of treatment and discharge options for these waters. The evaluation included consideration of other potential influents and the key contaminants for the Weldon Spring site.

EVALUATION

Potential Influents and Contaminants of Concern

The surface waters impounded at the chemical plant area constitute potential sources of contaminant releases. The raffinate pits contain various wastes from past processing and decontamination activities at the chemical plant, and Frog Pond and Ash Pond contain contaminants from past discharges and surface runoff, e.g., over contaminated soils nearby. Radioactive contaminants in these impounded waters include uranium and radium; chemical contaminants include metals such as arsenic and manganese and anions such as fluoride, chloride, and nitrate. The key contaminants for the treatment plant were determined by comparing the concentrations of contaminants in the surface waters impounded at the chemical plant area with potential effluent targets. A list of the contaminants with influent concentrations exceeding potential effluent targets was then reviewed to determine whether potential future influents might contain contaminants not already considered. Potential future influents that were considered included surface runoff or leachate collected in a pond at an adjacent storage area for waste material to be excavated from the quarry, decontamination water for vehicles associated with unloading the quarry waste at the storage area, and interstitial water collected from the dewatering of the raffinate pit sludges prior to their treatment, if required. The contaminants of concern determined from this process and their associated effluent targets are identified in Table 1.

TABLE 1 Contaminants Considered for Treatment to Reduce Concentrations to Potential Effluent Targets

Primary Contaminants ^a	Unit	Average Influent Concentration	Potential Effluent Target ^b	Secondary Contaminants ^c	Unit	Range of Influent Concentrations	Potential Effluent Target ^b
Arsenic	mg/L	0.09	0.05	Antimony	mg/L	<0.06 - 0.395	0.146
Manganese	mg/L	0.07	0.05	Beryllium	mg/L	<0.001 - 0.008	0.005
Selenium	mg/L	0.04	0.01	Chromium	mg/L	<0.001 - 0.194	0.05
Chloride	mg/L	778	250	Copper	mg/L	<0.001 - 3.7	1
Cyanide ^d	µg/L	30	5	Iron	mg/L	0.011 - 3.8	0.3
Fluoride	mg/L	4.6	2	Lead	mg/L	0.001 - 0.358	0.05
Nitrate (as N)	mg/L	1,500	10	Nickel	mg/L	0.001 - 0.174	0.1
2,4-DNT	µg/L	10	0.11	Sulfate	mg/L	70 - 2,220	250
Radium-226	pCi/L	184	5, combined	Thorium-230 ^e	pCi/L	1.6 - 760	15, minus radium-226
Radium-228	pCi/L	96		Thorium-232 ^e	pCi/L	1.1 - <110	15, minus radium-228
Total uranium ^f	pCi/L	1,416	100				

^a A primary contaminant is one for which the average concentration in the influent exceeded the potential effluent target; all primary contaminants require treatment in the water treatment plant. Listed concentrations represent the highest average values reported for the following influent sources: the raffinate pits, Frog Pond, Ash Pond, and the TSA collection pond — based on quarry water quality data.

^b Unless otherwise noted, targets were taken from federal drinking water standards (40 CFR Parts 141 and 143) and state of Missouri drinking water supply limits.

^c A secondary contaminant is one for which the potential effluent target was not exceeded by the average concentration of the influent but was exceeded by the upper end of the concentration range and may require treatment in the water treatment plant.

^d Cyanide was detected in early sampling of the raffinate pits and was therefore included in the preliminary design of the water treatment plant to be conservative, but it has not been detected in subsequent characterization sampling at the pits.

^e As gross alpha.

^f Total uranium = sum of uranium-234, uranium-235, and uranium-238, assumed to be present in their natural activity ratio of 1:0.046:1. The effluent target was derived from DOE radiation protection standards given in DOE Order 5400.5 (DOE 1990). By implementing the as low as reasonably achievable process, the level of uranium in the treatment plant effluent would be maintained at or below 100 pCi/L.

Source: Data from MacDonell et al. (1990).

Except for total uranium, effluent targets were taken from federal drinking water standards and state of Missouri drinking water supply limits. The DOE "as low as reasonably achievable" (ALARA) process was applied to the establishment of a treatment goal for uranium, the only primary contaminant for which no health-based standard has been promulgated. The uranium concentrations in some of the surface waters exceeded the limit of 550 pCi/L derived from DOE guidelines for discharges of total uranium to uncontrolled areas (DOE 1990). The analysis of potential unit operations for the treatment plant focused on the development of a system that could be designed and operated to reduce the level of residual uranium in the treated water to as far below 550 pCi/L as reasonably achievable, i.e., to 100 pCi/L and below. The design goal was established as 30 pCi/L; thus, the effluent target would be 100 pCi/L, with effluent concentrations ranging from 30 to 100 pCi/L.

Treatment System

Potential technologies for management of the contaminants in site surface waters were identified and screened for their specific applicability to the impounded surface waters at the chemical plant area in terms of technical feasibility and implementation. Eight broad treatment categories were identified as potentially applicable: (1) density separation, which includes clarification, pretreatment by equalization/detention, and flotation and flocculation, as appropriate; (2) coagulation/precipitation, which includes coagulant or lime addition and other chemical additions as required (e.g., for neutralization); (3) oxidation; (4) granular media filtration (filter press filtration was also considered potentially applicable for follow-on dewatering of process sludges); (5) ion exchange; (6) adsorption; (7) biological denitrification; and (8) vapor recompression/distillation (with follow-on mechanical drying for brine volume reduction). Each of these treatment technologies has been proven in field applications under conditions similar to those at the chemical plant area.

Five treatment system options were then developed for the proposed treatment plant. Options 1 through 4 are four-stage nondistillation alternatives that differ from each other with respect to their component processes for chemical addition and nitrate removal. For chemical addition, Options 1 and 2 use coagulant addition whereas Options 3 and 4 use lime treatment. For nitrate removal, Options 1 and 3 use land treatment whereas Options 2 and 4 use a fluidized bed reactor. Options 2 and 4 also include aeration for residual methanol removal and an additional clarification and granular media filtration step for suspended solids removal following nitrate removal in the fluidized bed reactor. Option 5 is primarily a two-stage distillation process that includes ion exchange. Adsorption as a polishing step to remove residual contaminants could be included for a specific waste stream as needed, and mechanical drying would be used to reduce waste volume. The four treatment stages and the removals targeted by component technologies are identified in Table 2; the unit operations and process flow schematics are illustrated in Figures 2 and 3.

TABLE 2 Removal of Contaminants Targeted by Staged Process Technologies^a

Treatment System Option	First-Stage Treatment				Second-Stage Treatment ^b
	Chemical Coagulation/Clarification	Lime Addition/Clarification	Oxidation	Distillation	Granular Media Filtration
1	As, Mn, other metals, Se, U, Th, Ra, F, SO ₄	- ^c	CN	-	SS
2	As, Mn, other metals, Se, U, Th, Ra, F, SO ₄	-	CN	-	SS
3	-	As, Mn, other metals, U, Th, Ra, SO ₄	CN	-	SS
4	-	As, Mn, other metals, U, Th, Ra, SO ₄	CN	-	SS
5	-	-	-	All	SS
Treatment System Option	Third-Stage Treatment ^d		Fourth-Stage Treatment ^b		
	Adsorption	Ion Exchange	Land Treatment	Fluidized Bed Reactor	
1	F, As, Se, U, Ra, organics	U, Th, Ra, As, Se, F, SO ₄ , NO ₃ , Cl	NO ₃ , Ra, U, organics	-	
2	F, As, Se, U, Ra, organics	U, Th, Ra, As, Se, F, SO ₄ , NO ₃ , Cl	-	NO ₃ , Ra, U, organics	
3	F, As, Se, U, Ra, organics	U, Th, Ra, As, Se, F, SO ₄ , NO ₃ , Cl	NO ₃ , Ra, U, organics	-	
4	F, As, Se, U, Ra, organics	U, Th, Ra, As, Se, F, SO ₄ , NO ₃ , Cl	-	NO ₃ , Ra, U, organics	
5	-	U, Th, Ra, As, Se, F, SO ₄ , NO ₃ , Cl	-	-	

^a Contaminants targeted for removal are defined as follows: As = arsenic; Cl - chloride; CN = cyanide; F = fluoride; Mn = manganese; NO₃ = nitrate; organics include 2,4-DNT, a primary organic contaminant for the proposed action; other metals = secondary contaminant metals; Ra = radium; Se = selenium; SO₄ = sulfate; SS = suspended solids; Th = thorium; U = uranium.

^b This treatment stage is associated only with nondistillation process options.

^c A hyphen indicates that the category is not applicable.

^d Ion exchange is a second-stage process for Option 5, a third-stage process for Options 2 and 4, and a fourth-stage process for Options 1 and 3.

Source: MacDonell et al. (1990).

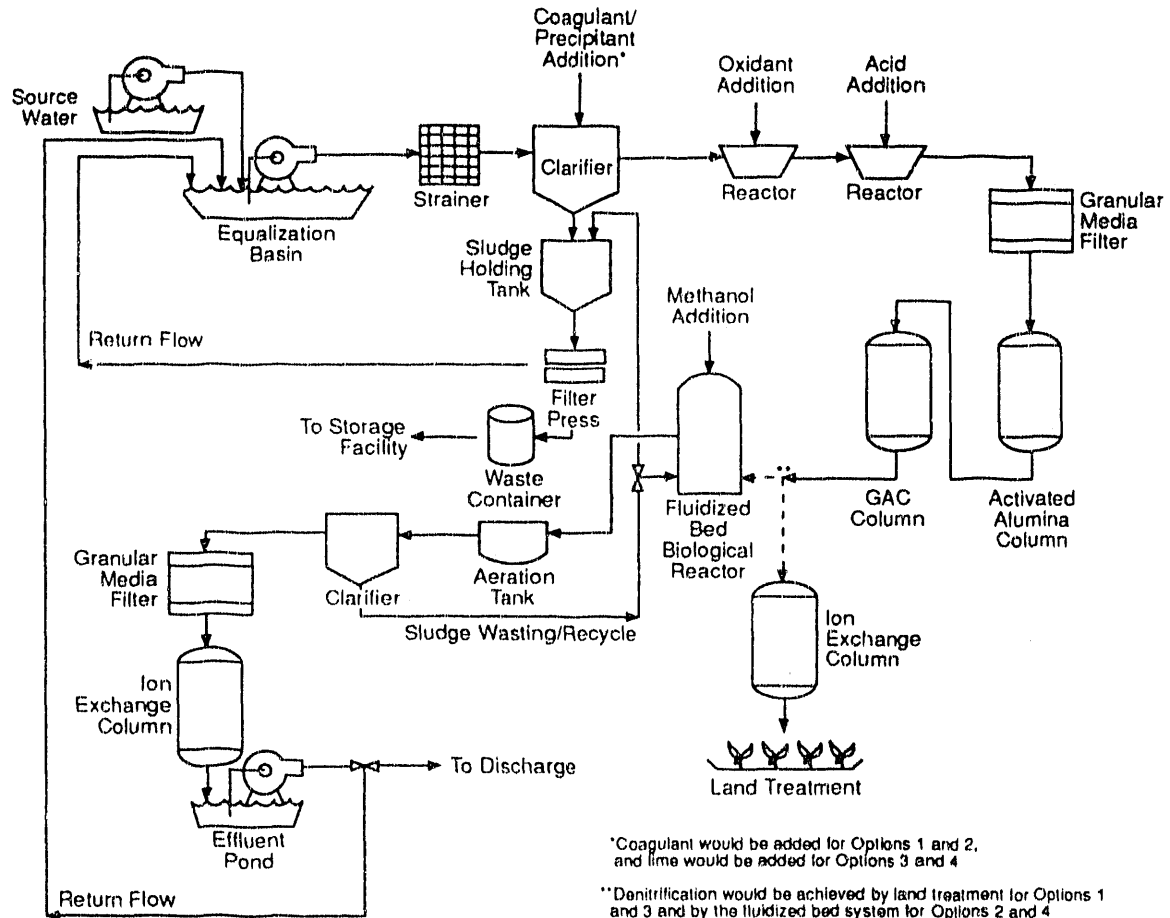


FIGURE 2 Unit Operations and Process Flow Schematic for the Nondistillation Options (Source: MacDonell et al. 1990)

The preferred treatment system was determined by evaluating these five options according to effectiveness, implementation considerations, and reasonable cost. Each of the options would reduce contaminant concentrations to meet appropriate effluent targets, and each could be constructed and operated in a safe manner with conventional equipment and standard procedures.

For the precipitation step, Options 1 and 2 (chemical coagulation) would have a slight advantage over Options 3 and 4 (lime treatment) because chemical coagulation has been shown to be effective for the types of contaminants present in the influent waters and because lime addition generates sludge that would be more voluminous and less straightforward to manage. Option 5 (vapor recompression/distillation) would generate the largest initial volume of waste, but mechanical drying would significantly reduce the final volume.

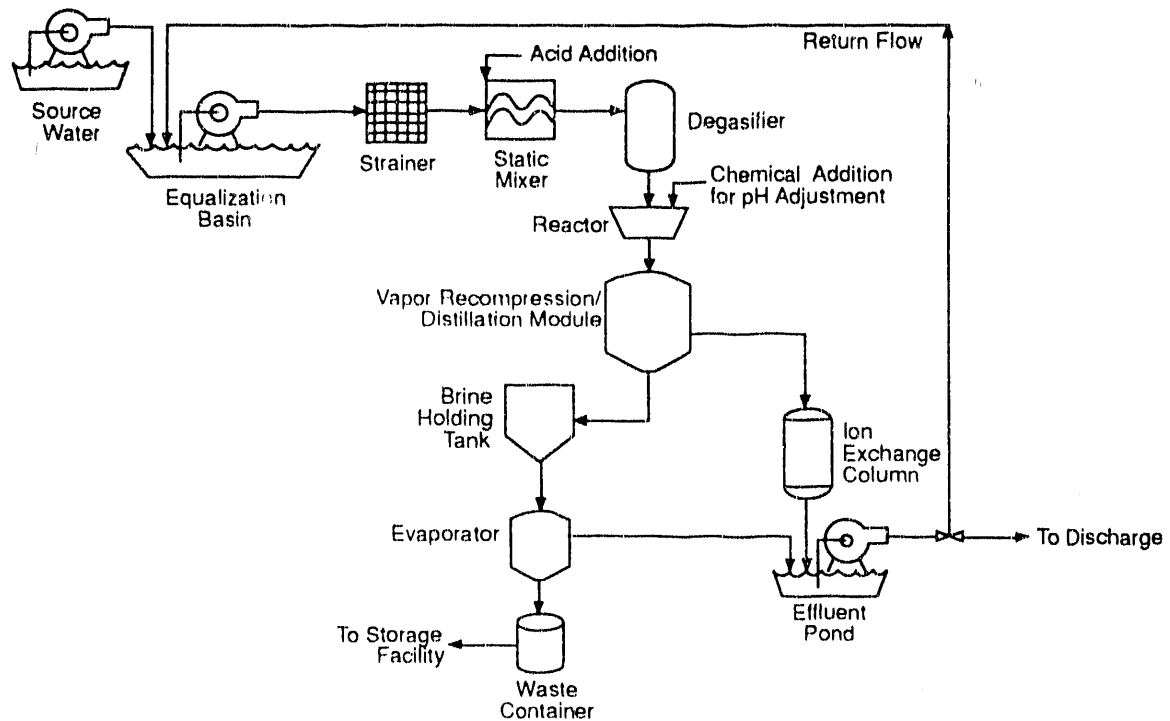


FIGURE 3 Unit Operations and Process Flow Schematic for the Distillation Option
 (Source: MacDonell et al. 1990)

The primary difference between the nondistillation options is related to the effectiveness and implementation of nitrate removal. Options 2 and 4 (fluidized bed reactor) would be much more straightforward to implement for denitrification than Options 1 and 3 (land treatment) because of the relative ease of construction and system control, which would reduce process sensitivity to site environmental conditions. The fluidized bed reactor system can tolerate shock loading whereas land treatment cannot. Also, temperature and pH can be readily controlled, and monitoring is relatively straightforward. In contrast, conservative operating conditions — including low loading rates and considerable land surface areas — would be required for land treatment to ensure appropriate final nitrate concentrations throughout the operating period. Biological denitrification can be adversely affected by cold, so operating temperatures would have to be maintained above 20°C (68°F) for effective treatment. In addition, subsurface drainage, monitoring, and runoff controls would be required for land treatment. Maintenance of these conditions year-round would be costly, and the effectiveness of contaminant removal would probably be compromised by environmental conditions and influent variability.

Implementation of Option 5 (vapor recompression/distillation) would be similar to that of Options 2 and 4 because standard equipment would be readily available. The effectiveness of vapor recompression/distillation, a physical system, would be very high relative to a combination physicochemical and biological system (Options 1 through 4)

because distillation can remove a wide range of contaminants over a range of influent concentrations. In fact, higher influent concentrations would increase process efficiency. Flows significantly lower than design could also be accommodated more easily by the distillation option compared with the nondistillation options. Once constructed, vapor recompression/distillation can be brought on-line within a matter of hours at maximum treatment efficiency. In contrast, start-up and optimization of the biological denitrification component of the nondistillation options can require days to weeks, and biological systems are much more difficult to maintain. Biological upsets that result in treatment failure are common when influent concentrations vary, which could occur when the raffinate pits were pumped down and/or other influents changed. Temperature, pH, and the presence of algae in the influent can also impact the effectiveness of denitrification. The distillation option would be much less sensitive to environmental conditions than the nondistillation options. Thus, the biological component of the nondistillation options would probably require numerous modifications to respond to influent variations whereas the distillation system would not.

The relative costs of the treatment system options were also considered in evaluating conceptual design treatment systems. A preliminary cost comparison was prepared for the five initial treatment options (which focused on treating only the raffinate pit waters) to provide general information for screening purposes. The estimated costs for the five options (as July 1988 dollars) were based on a design flow rate of 23 m³/s (100 gpm) for 24 hours per day, using standard cost guidance (Morrison-Knudsen Engineers 1988). The cost comparison is presented in Table 3.

TABLE 3 Comparative Costs of the Five Treatment System Options^a

Option	Capital (10 ⁶ \$)	Operation and Maintenance (10 ³ \$ per day)	Present Worth ^b (10 ⁶ \$)
1	2.17	1.18	2.75
2	1.97	1.46	2.69
3	2.17	1.20	2.77
4	1.97	1.48	2.71
5 ^c	2.01	1.50	2.83

^a Estimated costs as July 1988 dollars.

^b Expressed as the 10-year present worth, i.e., total cost over 10 years of operation discounted to present cost at a 10% discount rate.

^c Includes mechanical dryer for follow-on treatment.

Source: Data from Morrison-Knudsen Engineers (1988).

On the basis of comparing the five treatment system options and considering all potential influents to the treatment plant (including storm water that falls into the pits and ponds during the remedial action period and water used to decontaminate equipment and vehicles), none of the five options as evaluated was determined to be the optimal solution for treatment of the surface waters at the chemical plant area. The nitrate removal component of the physicochemical systems would be more susceptible to influent variations and would require more intensive optimization and maintenance compared with the vapor recompression/distillation option. An additional oxidation treatment step would be required to reduce cyanide, if present, to effluent target levels in the physicochemical systems but not in the distillation system. However, the vapor recompression/distillation system would require more energy, would be more expensive, and would produce a larger waste volume than the physicochemical systems. For contaminants other than nitrate and cyanide, distillation would be less cost effective than the more conventional wastewater treatment technologies employed to meet effluent targets in the physicochemical systems in Options 1 through 4.

Thus, a dual (hybrid) treatment system — comprised of the distillation option, Option 5, in parallel with most of the physicochemical components of Option 2 (all but oxidation) — was identified as the appropriate system (Figure 4). The hybrid system would be capable of treating the variety of potential influents and would provide treatment flexibility and optimize both system effectiveness and volume reduction. For example, waters that did not contain nitrate or cyanide would be treated in the conventional physicochemical system. Conversely, those waters requiring nitrate or cyanide removal would be directed to the distillation module of the plant. The capital cost of the dual system was estimated to be about \$2.99 million, and the annual operation and maintenance cost was estimated to average about \$230,000. This amount would vary on the basis of influent sequencing. The 10-year present worth value of the system was estimated to be about \$4.3 million (MacDonell et al. 1990). The construction and operation of the dual system would ensure applicability of the treatment process for all potential influents and would be cost-effective.

Discharge Options

Six options were considered for discharging treated water from the treatment plant. Under four of the options, the water would be released to the Missouri River as follows. Treated water would be pumped to the boundary of the chemical plant area and released to the Southeast Drainage for gravity flow in the channel (Option 1); or released through a buried pipe in the Southeast Drainage (Option 2); or released through a buried pipe along the ridge of the Southeast Drainage (Option 3). As another option, treated water would be pumped to a buried pipe along a haul road constructed between the chemical plant area and the quarry (Option 4); this road is part of a separate action to remove bulk waste from the quarry and transport it to the chemical plant area for short-term storage (until the overall disposal decision for site waste is reached). The haul road pipe would be connected to the discharge pipe for the quarry water treatment plant.

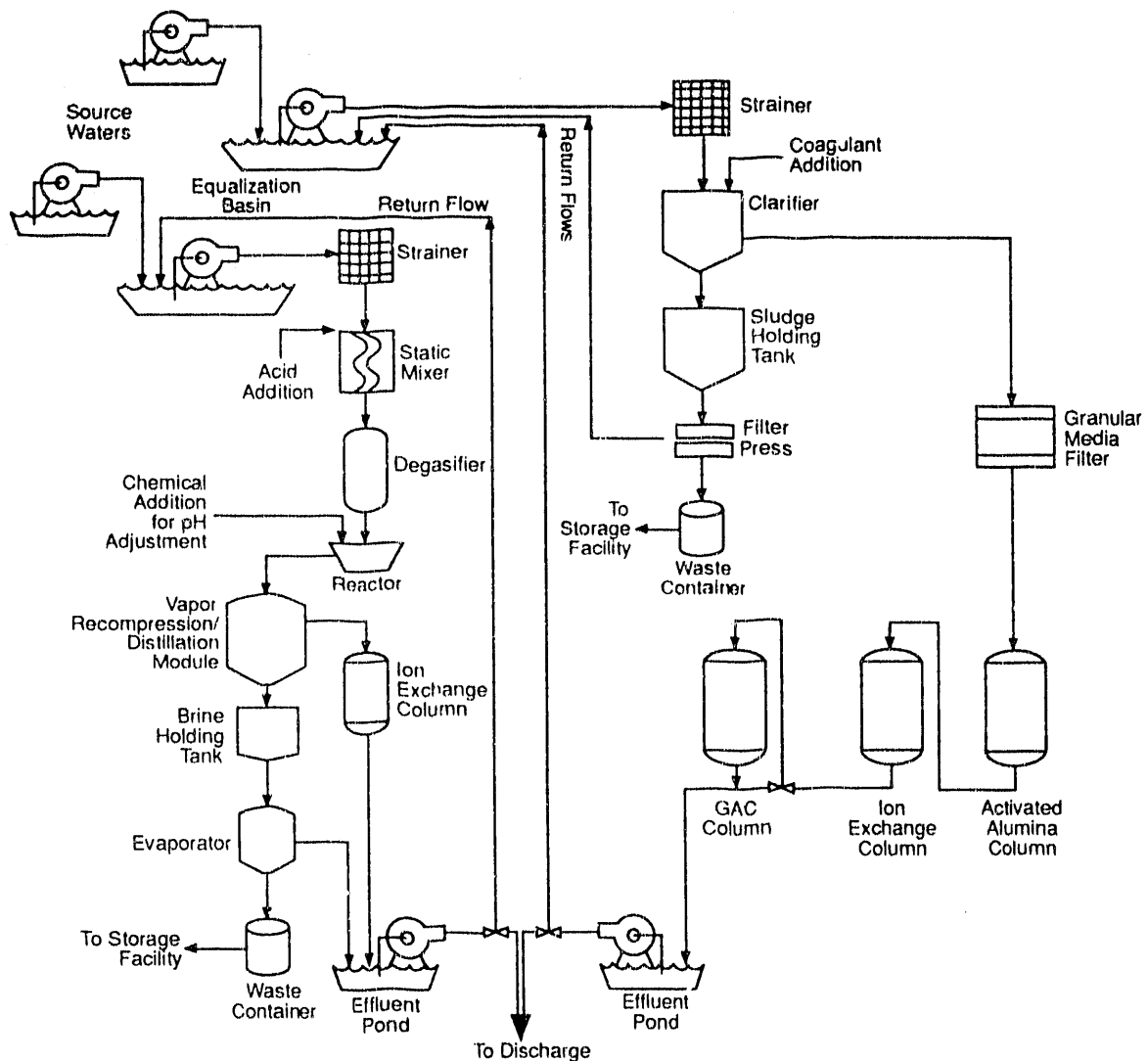


FIGURE 4 Preferred Treatment System for the Impounded Surface Waters at the Chemical Plant Area (Source: MacDonell et al. 1990)

Under the other two discharge options, the treated water would be released to the Mississippi River drainage basin via spray irrigation or evaporation ponds (Option 5) or overland flow (Option 6).

Under Options 1 through 4, the treated water would be released to the Missouri River. Option 1 (release by gravity flow through the Southeast Drainage) could be implemented in a straightforward and cost-effective manner. Neither the drainage channel nor the surrounding wildlife area would be disrupted because no construction activities would take place within the drainage. Discharge would be by gravity flow in the existing natural channel. The Southeast Drainage receives surface runoff from within its drainage boundary, which includes a small portion of the chemical plant area. The drainage

formerly received discharges of untreated waters from the process sewer line during the operating period of the chemical plant at rates of up to 14 m³/d (3,600 gal/d). These discharges resulted in some contamination of the sediment in the drainage, but contamination levels have been reduced by storm-water runoff over time. On the basis of the expected water quality and flow rate of the treatment plant effluent compared with current storm flows in the drainage, contaminant deposition or additional resuspension in the drainage was expected to be minimal. No channeling impacts were expected from the proposed discharge because of the physical nature of the drainage (rocky and already channeled due to historical and current flows) and the projected low flow rate compared with current storm flows in the drainage.

Options 2 and 3 (release through a pipe buried in the channel or along the channel ridge, respectively) would be difficult to implement because of the steep and rocky terrain of the drainage. Considerable work force and equipment allocations would be required. Costs would also be higher for these options than for Option 1 because of construction, pipe placement, and pipeline monitoring and maintenance requirements. Considerable habitat destruction would result from the clearing, trenching, and rock-cutting activities required for pipe burial, and wildlife and habitat in the Southeast Drainage would be displaced or destroyed. Similar impacts would result from construction of the access path required along the length of the pipeline for monitoring and maintenance activities. The DOE has obtained an easement from the Missouri Department of Conservation for the Southeast Drainage; however, the state manages the surrounding land as a wildlife area. Thus, the potentially significant adverse environmental impacts sustained in the Southeast Drainage under these discharge options might also impact adjacent land use.

Option 4 (release through a pipe buried along the haul road) would have similar technical constraints as Options 2 and 3 along certain portions of the pipe placement route. The haul road easement is narrow and would be concurrently used by truck traffic from the quarry during part of the operational period of the water treatment plant. Option 4 would cost considerably more than Options 2 and 3 because of additional piping, installation, and maintenance requirements (the total distance over which the pipe would be required is more than twice the length of the Southeast Drainage). Environmental disturbance would also occur, although not to the same extent as for Options 2 and 3.

Under Options 5 and 6, the treated water would be released to the Mississippi River drainage basin. Option 5 (use of spray irrigation or evaporation ponds) is constrained by local environmental conditions, i.e., the net balance between precipitation and evaporation, and the limited area of land available to receive the required effluent volume. Much of the land within the chemical plant area is excluded from application of spray irrigation because the water would percolate through contaminated soil. Also, land dedicated to spray irrigation would be intermittently unable to receive the water at the required rate, e.g., due to saturated or frozen conditions. Similar difficulties are associated with evaporation ponds. The environmental conditions in the area — including

low evaporation rates, relatively cold winters, and humid summers — and limited land availability would compromise the effectiveness and implementability of this option.

Under Option 6 (overland flow), the effluent would flow through small creeks, springs, and recreational lakes located within the adjacent Busch Wildlife Area. These waters feed Dardenne Creek, which flows northward through the towns of St. Peters and St. Charles and eventually into the Mississippi River. Dye-tracing studies conducted by the Missouri Department of Natural Resources (1989) have identified a complicated and extensive system of groundwater-surface water exchanges off-site in the Mississippi River drainage system. For this reason, and because the effluent would flow through recreational and residential areas, administrative difficulties would be associated with implementing this option, and associated monitoring costs would probably be high.

Option 1, release of the treated water to the Missouri River via gravity flow in the Southeast Drainage, was identified from this analysis as the most appropriate. This option would result in minimal environmental disturbance and could be implemented in a straightforward manner at a reasonable cost. Subsequent to the decision to release the treated water to the Southeast Drainage, flow studies were conducted in the drainage as part of detailed design to quantify the potential for contaminant resuspension and/or dissolution from the contaminated sediment as a result of the effluent discharge (MK-Ferguson Company and Jacobs Engineering Group 1992). Uncontaminated waters were released to the drainage in the upper part of the channel and the resulting uranium concentration was measured at the confluence of the drainage with the Missouri River. These studies showed that the uranium concentration increased from the initial effluent concentration as the water passed through the drainage, indicating some resuspension/dissolution of the uranium contamination within the drainage; however, the level of uranium at the confluence was comparable to the level that occurs naturally in the drainage as a result of storm flows. Because these levels exceed the level to which the site waters will be treated, additional discharge options are being evaluated to limit the potential for any incremental contaminant mobilization in the drainage prior to the cleanup decision for the drainage (expected within the next several years).

CONCLUSION

To address potential risks associated with contaminated surface waters impounded at the chemical plant area of the Weldon Spring site, the conceptual design of the water treatment system was based on potential influents and contaminants of concern. A dual treatment system was identified for the proposed treatment plant, one process scheme comprising physicochemical unit processes and the other comprising a distillation system. This dual system is expected to address the variety of potential influents with differing contaminant characteristics in an optimal, cost-effective manner.

Discharge options for the treated effluent from the plant were evaluated on the basis of potential environmental impacts, effectiveness, implementability, and cost. The selected option was to release the treated water to the Missouri River via gravity flow in

the existing Southeast Drainage channel. Subsequent analyses during the detailed design phase indicated that existing contamination in the drainage sediment contributes incremental uranium concentrations to the drainage flow at the design effluent flow rates for the treatment plant, comparable to those in natural storm flow in the channel. Further evaluation of discharge options is ongoing.

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