

**INTEGRATION POINT ASSESSMENT PROVIDES A DECISION TOOL FOR
IMPLEMENTING A REMEDIATION STRATEGY AT BEAR CREEK VALLEY AT
THE OAK RIDGE RESERVATION, OAK RIDGE, TENNESSEE.**

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ABSTRACT

The integration point (IP) assessment provided a tool for making a remedial decision on a large, watershed-basis. This tool contributed to the selection of the remedial alternative in the record of decision (ROD) for Bear Creek Valley at the Oak Ridge Reservation, Oak Ridge, Tennessee. The IP assessment decision tool allowed for a quantitative measure of the reduction in contaminant flux and associated human health risk in surface water at the exposure point in the valley, downgradient from all sources of contamination (i.e., the integration point). Remedial alternatives developed in the feasibility study were evaluated as to their effectiveness in mitigating contaminant migration, and thus risk, from the various sources through the surface water pathway. The remedial alternatives, made up of combinations of actions ranging from extensive source actions (e.g., in situ immobilization or waste excavation) to simple hydraulic isolation (e.g., impervious caps), were evaluated using the IP assessment model. Flux reduction factors associated with specific actions or collections of actions at specific waste units were developed based on conceptual models, engineering evaluations, and best professional judgement. These values, ranging from 40 to 99 percent, were input into the IP assessment model with a resultant percent reduction in flux and associated risk from the contributing sites. The resultant total flux reduction at the integration point for each of the five remedial alternatives evaluated, ranged from 69 to 97 percent. Additionally, using total present worth capital cost and the flux reduction estimates, a cost/benefit analysis was performed. The cost per delta unit flux reduction ranged from a low of \$4.3 million to a high of \$33 million. This analysis concluded that the lowest cost alternative (\$26 million), provides about the same flux reduction as the highest cost, most aggressive alternative and provides similar risk reduction. Thus, a cost-effective remedial action that is protective of human health and the environment, complies with applicable and relevant and appropriate requirements, and supported by both the regulators and the public, was selected in the ROD for Bear Creek Valley.

INTRODUCTION

The remediation strategy for Bear Creek Valley at the Oak Ridge Y-12 Plant in Oak Ridge, Tennessee consists of a combination of source control actions and migration control actions. The remedial investigation conducted for the Bear Creek Valley identified three primary

waste management units contributing contaminants to Bear Creek, which subsequently carries these contaminants out of the waste management area. These include: the S-3 Site; the Oil Landfarm Area; and the Bear Creek Burial Grounds (BCBGs). Contaminated groundwater at these locations migrates along geological strike to nearby tributaries of Bear Creek (i.e., north tributary [NT]-1, -3, -7, and -8east). Waste sources within these main waste units contribute to contamination in groundwater in Bear Creek Valley and subsequent contamination in Bear Creek.

Currently, Bear Creek Valley, located near the center of the ORR, is inaccessible to the public. The eastern portion of the valley west of the Y-12 Plant, once used for waste disposal, is now subject to periodic maintenance and monitoring of the closed waste management areas. The remediation strategy for Bear Creek Valley is premised on the fact that known waste sources in the eastern portion of Bear Creek Valley are releasing contaminants into the environment that subsequently migrate down the valley via the surface water pathway. These sources have been shown to be contributing varying amounts of contaminants in Bear Creek Valley to locations downgradient of the portion of the valley used for waste disposal and management. Results of the remedial investigation (1) are as follows:

- At the S-3 Site nitrate and radionuclides are released via discharge from shallow groundwater into NT-1, NT-2 and directly into upper Bear Creek adjacent to the site;
- At the BYBY radionuclides are discharged from the shallow groundwater into NT-3; and
- At the BCBGs volatile organic compounds and radionuclides are discharged from the shallow groundwater into NT-7 and NT-8east.

EVALUATION OF ALTERNATIVES USING THE IP ASSESSMENT MODEL

The integration point (IP) assessment model was originally developed to evaluate the relative importance of contaminant fluxes from various sources within the valley by comparing them to each other in terms of their contribution to total risk at the integrator point. In other words, contaminant fluxes, converted to flow-weighted average concentrations in surface water in order to calculate risk values, could be directly compared and thus, ranked in order of importance. The results of the IP assessment model suggest the following:

- Most of the contaminants migrating off site via surface water comes from BYBY via NT-3 (~53%), while the S-3 Site and BCBGs contribute approximately the same, ~23% and ~20%, respectively.
- Volatile organic compounds (i.e., tetrachloroethene and trichloroethene) migrate from waste sources (primarily the BCBGs), however it is estimated that >80% of the mass detected in tributaries volatilizes prior to reaching the integrator point.
- Uranium poses the greatest health hazard, contributing 98% of the total risk at the integrator point.

Ten remedial alternatives were initially developed and screened in the feasibility study (2). Of these, five were carried forward for detailed analysis to address the contamination

migrating from Bear Creek Valley sources. The alternatives evaluated and a brief description include:

1. Alternative 3: Aggressive surface water and groundwater actions with ex situ water treatment;
2. Alternative 5: Aggressive source actions, no water treatment;
3. Alternative 7: Source actions with surface water collection and ex situ water treatment;
4. Alternative 9: Surface water and groundwater actions with ex situ water treatment; and
5. Alternative 10: Source actions with no water treatment.

Combinations of source actions and migration control actions make up these five alternatives. Additionally, following discussion between DOE, the regulators, and the public, a Preferred Alternative was developed. This alternative consists of the same actions as Alternative 5 except for actions at source units in the BCBGs. The Preferred Alternative was evaluated similarly as the above mentioned alternatives, although outside of the feasibility study, since it was developed after finalizing the feasibility study. Table 1 summarizes the remedial actions associated with each of the above alternatives (designated as Alternative #-Action #, for example: A3-1). The emphasis of these actions is to protect human health and the environment from releases currently occurring, or may occur in the future.

The remedial alternatives for Bear Creek Valley are designed to meet one of two remedial action objectives (RAOs). The major element of the RAOs is land use, particularly in the area just west of the waste disposal sites. RAO 1 is to protect an unrestricted land use receptor (i.e., a residential receptor) from risk exceeding 1×10^{-5} , while RAO 2 is to protect a recreational receptor from risk exceeding 1×10^{-5} . To facilitate development of the RAOs, the valley has been divided into three zones, with Zone 1 being the area containing all of the waste units. Each alternative was then developed around tailored cleanup objectives proposed for each zone. The major difference in the RAOs is the land use for Zone 2, which extends from the western edge of Zone 1 to an area approximately 1 mile west that is currently unimpacted by any contamination migrating from the waste sources (i.e., Zone 3). One RAO is based on the land use in Zone 2 being unrestricted (i.e., residential use), while the other RAO is based on land use in Zone 2 being recreational, while unrestricted land use is moved further west (i.e., to Zone 3). Alternatives 3 and 7 are developed around the first RAO and Alternatives 5, 9, 10, and the Preferred Alternative are developed around the second RAO.

Table 1. Summary of alternative actions by site

Alternative	Waste Site	Action Number	Action
3	S-3	A3-1	Shallow groundwater interceptor trenches in NT-1, NT-2, and upper Bear Creek and groundwater extraction wells between NT-1 and NT-2
	BYBY	A3-2	Excavate source material and dispose, install cap
	BCBGs	A3-3	Maintain existing caps, upgradient stormflow diversion trenches, enhanced leachate collection, shallow groundwater collection trench at NT-7 and NT-8E, and groundwater extraction wells southwest of BCBGs
5	S-3	A5-1	Passive <i>in situ</i> shallow groundwater treatment trench at S-3 Ponds and NT-1
	BYBY	A5-2	Excavate source material and dispose, install cap
	BCBGs	A5-3	Maintain existing caps, <i>in situ</i> stabilization of some areas, upgradient stormflow diversion trenches and passive <i>in situ</i> shallow groundwater treatment trench at NT-7 and NT-8E, or limited to full excavation and disposal of buried waste
7	S-3	A7-1	Shallow groundwater interceptor trench in upper Bear Creek and tributary collection at NT-2 and NT-3
	BYBY	A7-2	Excavate source material and dispose, install cap
	BCBGs	A7-3	Maintain existing caps, upgradient stormflow diversion trenches, enhanced leachate collection, groundwater extraction wells southwest of BCBGs, and surface water collection at NT-7 and NT-8
9	S-3	A9-1	Surface water collection at NT-1 and NT-3
	BYBY	A9-2	Surface water collection for NT-3
	BCBGs	A9-3	Maintain existing caps, upgradient stormflow diversion trenches, passive <i>in situ</i> groundwater treatment trench at NT-7 and NT-8E
10	S-3	A10-1	No actions
	BYBY	A10-2	Excavate hot spots and install cap
	BCBGs	A10-3	Maintain existing caps, upgradient stormflow diversion trenches
Preferred Alternative	S-3	PA-1	Passive <i>in situ</i> shallow groundwater treatment trench at S-3 Ponds and NT-1
	BYBY	PA-2	Excavate hot spots, dispose, and install cap
	BCBGs	PA-3	Passive <i>in situ</i> shallow groundwater treatment trench at NT-7 and NT-8E. Other actions deferred to follow-up remedial action

As part of the detailed analysis of alternatives, the risk evaluation of remedial alternatives (which is used in part to evaluate the overall protection of human health, one of the nine CERCLA evaluation criteria) was performed using the IP assessment model. This analysis provided a means to compare the alternatives in terms of overall risk reduction. Additionally, by using total present worth capital costs for the alternatives and the contaminant flux reduction estimates provided by the model, a cost/benefit evaluation identified the most cost-effective remedial alternative for Bear Creek Valley.

The IP assessment model was used as a tool to evaluate the remedial alternatives in terms of their effectiveness in reducing contaminant fluxes at the integrator point. Because uranium, technetium-99, PCE and TCE contribute most to the risk at the integrator point, only these constituents were considered in the alternatives evaluation using the IP assessment model. However, as previously mentioned, uranium contributes 98% to the risk at the integration point,

and is therefore the principal constituent of concern in reducing risk to human health. Therefore, for the remainder of this discussion, only uranium is considered in terms of evaluating remedial alternatives.

Contaminant fluxes calculated by the IP assessment model were adjusted by the effectiveness of a specific remedial action, or groups of actions, in a source area (e.g., the BYBY) to reduce uranium mass flux from a specific tributary (e.g., NT-3). The reduced contribution from each tributary when scaled and summed provided the total cumulative reduction in uranium flux at the integrator point. Table 2 provides the flux reduction factors associated with the specific remedial actions identified in Table 1. These estimates are designed for expected conditions regarding the fate and transport of contaminants in Bear Creek Valley, the known or assumed conditions of the various contaminated media, and the most likely future conditions of environmental media based on transport and flow modeling. Additionally, the effectiveness of these remedial actions in reducing uranium flux is based on evaluation considering the site conceptual model, fate and transport modeling, and available information from past experiences at other sites. Below is a brief description of the actions and supporting information regarding the reduction factors by waste site assumed for each collection of actions developed for the remedial alternatives.

S-3 Site Actions

- A3-1** This action includes the installation of shallow groundwater collection trenches along NT-1, NT-2, and upper Bear Creek to capture contaminated shallow groundwater being released to the surface, as well as shallow and deep groundwater extraction wells downgradient of the S-3 site in the contaminated plume. Groundwater capture and treatment is a proven technology, although the overall efficiency in this application is dependent on effective capture of contaminated water being discharged to the surface. Given the nature of these actions directed at the contaminated plume, along with ex situ water treatment, a contaminant flux reduction of 95% was assumed.
- A5-1** This action consists of passive groundwater treatment trenches that consist of the same shallow groundwater collection trenches as in A3-1, however *in situ* treatment, with a reactive media (e.g., peat moss or iron filings), is utilized with the treated water flowing through the trench and discharging to surface water. Reactive media have been used in trenches to intercept and treat radiologically contaminated shallow groundwater at other ORR sites, with removal efficiencies of up to 95%. The overall efficiency of such water treatment systems, however, will be dependent on effective capture of contaminated water being discharged to the surface and on the use of an appropriate reactive media chosen through testing. Because of the likely reduced efficiency of removal of uranium with a reactive media, a contaminant flux reduction of 80% was assumed.

Table 2. Summary of uranium flux reduction factors for alternative actions by site

Waste Site	Alternative					Preferred Alternative
	3	5	7	9	10	
S-3 Ponds	A3-1 95%	A5-1 80%	A7-1 90%	A9-1 60%	A10-1 0%	PA-1 80%
BYBY	A3-2 90%	A5-2 90%	A7-2 90%	A9-2 60%	A10-2 90%	PA-2 90%
BCBG	A3-3 90% for NT-8E 80% for NT-7	A5-3 95%-99% for NT-8E 80%-99% for NT-7	A7-3 95% for NT-8E 90% for NT-7	A9-3 85% for NT-8E 80% for NT-7	A-10 50% for NT-8E 25% for NT-7	PA-3 80% for NT-8E 80% for NT-7

A7-1 This action consists of a combination of surface water collection from NT-1 and NT-2 and a shallow groundwater collection trench along upper Bear Creek with ex situ water treatment. While nearly all of the contaminants released to NT-1, NT-2, and upper Bear Creek should be captured via these actions, contaminants moving in the deeper system and discharging to the surface downgradient would not be captured. Therefore, a reduced contaminant reduction efficiency (90%) over that assumed for A3-1 is assumed for these actions.

A9-1 This action consists of surface water collection from NT-1 only. Constituents moving into upper Bear Creek would not be captured since no action will occur for this pathway. Therefore a reduced contaminant reduction efficiency (60%) over that assumed for A7-1, is assumed for this action.

A10-1 No actions are included in Alternative 10 at this site, therefore contaminant reduction efficiency is 0%.

PA-1 Same as A5-1.

BYBY Actions

A3-2 Buried source material in the BYBY is known to contribute to uranium contamination in NT-3. Removing this source material that is in contact with the shallow water table is estimated to result in a 90% reduction in uranium flux from BYBY.

A5-2 Same as A3-2.

A7-2 Same as A3-2.

A9-2 This action consists of surface water collection at NT-3 and the installation of a multilayer cap to reduce infiltration of precipitation into the buried source material. Mass balance calculations using the *Hydrogeologic Evaluation of Landfill Performance* (HELP) model have shown that precipitation infiltration rates may be reduced up to 95 percent by multilayer caps. However, since nearly half of the source material will remain in contact with groundwater and a flow path directly into adjacent Bear Creek may still exist, reduced flux reduction efficiency (60%) is assumed for this action.

A10-2 Same as A3-2.

PA-2 Same as A3-2

Burial Ground Actions

A3-3 This actions consist of a combination of upgradient stormflow diversion trenches to reduce precipitation moving through the shallow ground interval and then through the buried waste, enhancement of the existing leachate collection system to capture more leachate from the primary source in the BCBGs, multilayer caps installed on all waste, shallow groundwater collection trenches along NT-8east and NT-7 and a line of groundwater extraction wells downgradient of the sources to reduce contaminant discharge into NT-8. The flux reduction efficiencies of these actions for sources contributing to NT-8east and NT-7 are assumed to be 90% and 80%, respectively.

A5-3 Actions under Alternative 5 consist of a subset of three groups of actions. (1) This action consist of a combination of upgradient stormflow diversion trenches as described for A3-3, in situ stabilization of wastes in units that contribute most to contaminant migration, multilayer caps installed on waste sources not previously capped, and passive *in situ* shallow groundwater treatment trenches in NT-8east and NT-7 as described for A5-1. The flux reduction efficiencies of these actions for sources contributing to NT-8east and NT-7 are assumed to be 95% and 80%, respectively. (2) This action consists of a combination of upgradient stormflow diversion trenches as described for A3-3, replacing *in situ* stabilization with waste excavation and disposal, multilayer caps installed on waste sources not previously capped, and passive in situ groundwater treatment trenches in NT-8east and NT-7 as described for A5-1. Given the action to excavate some waste as opposed to stabilizing it in place, slightly higher reduction efficiency was assumed for this subset of Alternative 5. The flux reduction efficiencies of these actions for sources contributing to NT-8east and NT-7 are assumed to be 98% and 80%, respectively. (3) This action consists of excavating all buried waste in the BCBGs only. Given that all waste would be removed from the environment, both of the flux reduction efficiencies for NT-8east and NT-7 are assumed to be 99%.

- A7-3** This action consists of upgradient stormflow diversion trenches as described for A3-3, multilayer caps installed only on waste units not previously capped, enhancement of the leachate collection system as described for A3-3, surface water collection and treatment for NT-8east and NT-7, and a line of groundwater extraction wells as described for A3-3. The flux reduction efficiencies of these actions for sources contributing to NT-8east and NT-7 are assumed to be 95% and 90%, respectively.
- A9-3** This action consists of same actions as described for A7-3 except that surface water collection and treatment is replaced with passive *in situ* shallow groundwater treatment trenches in NT-8east and NT-7 as described for A5-1. The flux reduction efficiencies of these actions on sources contributing to NT-8east and NT-7 are assumed to be 85% and 80%, respectively.
- A10-3** This action consists of the same actions as described for A9-3 without the passive *in situ* shallow groundwater treatment trenches in NT-8east and NT-7. The flux reduction efficiencies of these actions on sources contributing to NT-8east and NT-7 are assumed to be 50% and 25%, respectively.
- PA-3** This action consists only of installation of passive *in situ* shallow groundwater treatment trenches in NT-8east and NT-7 as described for A5-1. The combined flux reduction efficiencies of these actions on NT-8E and NT-7 are both assumed to be 80%.

RESULTS OF THE ALTERNATIVES EVALUATION USING THE IP ASSESSMENT MODEL

The IP Assessment model was used as a tool to evaluate the remedial alternatives developed for Bear Creek Valley in terms of potential reduction in contaminant flux from sources into surface water and ultimately to the integrator point downgradient of the sources. Implementing the actions described in Table 1 and using the flux reduction factors presented in Table 2 the IP assessment model gives resultant contaminant fluxes at the integrator point for all of the alternatives. As previously mentioned, because the primary constituent contributing to risk at the integrator point is uranium, the remainder of this discussion only considers uranium in relation to flux reduction. Further, as discussed above, three of the six alternatives evaluated using the IP assessment model considered unrestricted land use begins at the integrator point, while for the remainder unrestricted land use begins at a location approximately 1 mile downstream of the integrator point (at BCV 7.3). Therefore, an attenuation factor of 3 was assumed based on surface water flow differences between that location in Bear Creek at the IP and the location at BCK 7.3.

Table 3 presents the results of the IP Assessment model for each alternative in terms of resultant uranium flux and associated human health cancer risk at the unrestricted land use zone appropriate to the particular alternative. As previously noted, land use is unrestricted in Zone 2 for Alternatives 3, 7, and 9, while that for Alternatives 5, 10, and the Preferred Alternative is in

unrestricted in Zone 1. Also shown are the fractions that the final human health risk at the unrestricted land use zone for each alternative are below the remedial goal established for Bear Creek Valley (i.e., 1×10^{-5}).

As shown in Table 3, the current uranium flux measured at the integrator point is 109 kg/yr. This mass of uranium, converted to a concentration, is associated with a human health cancer risk at the integrator point of 5×10^{-5} , assuming exposure to surface water in Bear Creek consistent with domestic water use (i.e., ingestion, dermal absorption and inhalation of volatile organic compounds during water use). The risk value associated with the no action alternative is five times greater than the remedial goal established for cleanup of Bear Creek Valley. Additionally, it can be seen that all of the remedial actions reduce the uranium flux, although the extent of this reduction varies with the combination of actions designed for the particular alternatives. The post action uranium fluxes vary from 3 kg/yr for the most robust alternative (i.e., complete excavation of buried waste) to 34 kg/yr for the least robust action (i.e., multilayer caps only on sources and some source excavation). Further, total human health cancer risk at the applicable unrestricted land use zone for the alternatives varies from 1×10^{-6} to 1×10^{-5} , all values of which are either below or right at the remedial goal established for Bear Creek Valley.

Table 3. Uranium Flux and Associated Risk Estimated Using the Integration Point Assessment Model

IP Assessment Model Result	Alternative						
	No Action	3	5	7	9	10	Preferred Alternative
Uranium Flux (kg/yr)	109	22	5 – 3	34	25	16	6
Associated Risk	5×10^{-5}	8×10^{-6}	2×10^{-6} – 1×10^{-6}	1×10^{-5}	8×10^{-6}	7×10^{-6}	2×10^{-6}
Ratio of Post Action Risk to Remedial Goal	NA	1.2	5—10	1	1.2	1.4	5

DISCUSSION OF THE RESULTS OF THE ALTERNATIVES EVALUATION

The IP assessment model was part of the detailed evaluation of remedial alternatives in the feasibility study, specifically overall protection of human health and the environment. It provided one of several means for comparison of the alternatives, in order to formulate the best option for remedial action in Bear Creek Valley.

Partly on the basis of the information from the IP Assessment model, the Preferred Alternative was chosen as the selected alternative for codifying in the record of decision. This alternative was justified partly on the basis of an additional analysis conducted in conjunction with the IP assessment model. This additional analysis included combining the results of the IP assessment model with total present worth capital cost of the alternatives to determine the cost per delta unit flux reduction. Table 4 presents the results of this analysis.

As shown in Table 4, total present worth of the alternatives evaluated for Bear Creek Valley range in cost from \$26 million to \$399 million. Additionally it is shown that the lowest cost alternative, the Preferred Alternative, provides a comparable uranium flux reduction as the highest cost, most robust alternative (i.e., a subalternative of Alternative 5 which considered complete excavation of all buried waste). As previously noted, the Preferred Alternative is essentially Alternative 5 without source actions at the waste units in the BCBGs. It can be concluded from this that the source units in the BCBGs do not contribute significantly to current uranium flux in Bear Creek Valley. This information supported the decision to defer actions at the source units in the BCBGs to a future ROD for Bear Creek Valley.

Table 4. Remedial Alternative Risk versus Cost Evaluation

Alternative	Total Present Worth Capital Cost	Post-action Uranium Flux at Unrestricted Land Use Zone (kg/yr)	Cost per Delta Unit Uranium Flux Reduction
3	\$33M	22	\$6.5
5	\$104M—\$399M	3—5	\$14—\$33M
7	\$38M	34	\$12M
9	\$38M	25	\$6.4M
10	\$27M	16	\$19M
Preferred Alternative	\$26M	6	\$4.3M

Also shown on Table 4 are the costs per delta unit uranium flux reduction (i.e., the cost for each change in unit of uranium flux). These values ranged from a low of \$4.3 million for the Preferred Alternative to a high of \$33 million for the Alternative 5 subalternative. This analysis concluded that the lowest cost alternative (i.e., the Preferred Alternative) at \$26 million costs less per delta unit uranium flux reduction than the other alternatives, while achieving comparable uranium flux reduction. Thus, a cost-effective remedial action that is protective of human health and the environment, complies with applicable and relevant and appropriate requirements, and supported by both the regulators and the public, was selected in the ROD for Bear Creek Valley.

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REFERENCES

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