FIRST, DO NO HARM

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Abstract. There is an emerging awareness of the importance of sustainability and an integrated cross-cutting approach to environmental policy development. These trends along with technical and scientific developments underpin a variety of new environmental clean-up paradigms.

Central to these new paradigms are new metrics for evaluating remedial actions with respect to environmental burden and collateral damage. For example, if we define water intensity as the amount of water necessary to remove one pound of contaminant we can then evaluate a groundwater remediation system with regard to resource conservation. Likewise we can evaluate the energy efficiency of a groundwater remediation system by studying the energy intensity or kWhr/pound of contaminant removed. And finally, the carbon intensity (lb CO_2/ lb contaminant) can be determined from the energy intensity using readily available data from the power industry.

This paper introduces this new type of thinking through the analysis of a typical groundwater remedial action and relates it to the various spatial and temporal concentration regimes within a plume of contaminated groundwater and its' subsequent remediation. This new paradigm is also extended to other environmental actions and policies by considering the significance of risk transfer from one media to another.

INTRODUCTION

The Safe Drinking Water Act (SDWA) was originally passed by Congress in 1974 to protect public health by regulating the nation's public drinking water supply. In this form the SDWA was used to unsure that water delivered to Americans by public water supplies was safe to drink. The law was amended in 1986 and 1996 and now requires many actions to protect drinking water and its sources: rivers, lakes, reservoirs, springs, and ground water wells. The 1996 amendments greatly enhanced the existing law by recognizing source water protection, operator training, funding for water system improvements, and public information as important components of safe drinking water. This approach ensures the quality of drinking water by protecting it from source to tap.

SDWA authorizes the United States Environmental Protection Agency (US EPA) to set national health-based standards for drinking water to protect against both naturally-occurring and man-made contaminants that may be found in drinking water. These standards are promulgated in the form of a Maximum Contaminant Level (MCL) (the maximum amount of a contaminant allowed in water delivered to a user of any public water system) or a Treatment Technique (TT) (required procedure or level of technological performance set when there is no reliable method to measure a contaminant at very low levels).

ENVIRONMENTAL BURDEN AND RISK TRANSFER

National Primary Drinking Water Regulations (NPDWRs or primary standards) are legally enforceable standards that apply to public water systems and are the clean-up goals for RCRA and CERCLA groundwater remedial actions. Additional goals for groundwater remediation include hydraulic containment of contaminated groundwater, removal of contaminant mass, risk reduction, and the reduction of contaminant flux. These goals give no consideration to environmental burden of the remedial process or the value of *in-situ* services groundwater provides such as buffering against periodic shortages in surface water, prevent or minimize subsidence of the land surface due to groundwater withdrawals, protection against sea-water intrusion, facilitate habitat and ecological diversity, and provide discharge to support recreational activities. Furthermore, the remediation goals are often in direct opposition to sustainability goals such as natural resource preservation, energy conservation, reduction in green house gas emissions, maximizing recycle/reuse, and minimize footprint.

Additional environmental burdens derive from risk transfers that occur during remediation. For example, volatile contaminants are commonly stripped from groundwater using air and the contaminated air is subsequently emitted to the atmosphere resulting in a risk transfer from the SDWA to the Clean Air Act (CAA). Similarly sorbents used to remove contaminants from groundwater are disposed of in a hazardous waste landfill. In this case the risk is transferred from the SDWA to the RCRA. And finally, risk is transferred from CERCLA to RCRA and the CAA during the disposal of waste generated in the process of remediation of legacy waste sites.

There are many cases of this type of risk transfer in which a policy that is developed and implemented for a target problem is unaware, or unresponsive to, the collateral impacts on the "risk receiver." For example, requiring the addition of large quantities of oxygenates, such as methyl tert butyl ether, to gasoline to improve air quality ultimately led to contamination of soil and groundwater by this relatively long-lived recalcitrant contaminant. Risk was transferred from the air (CAA) to the groundwater (SDWA). What were the alternatives? Was there an alternative that would better meet both goals? In general, environmental technologies that use strong chemical reagents or large amounts of energy reduce local contamination levels, but transfer risk to the broader environment through energy use and/or ecological destruction – factors that are not traditionally considered in either the technology selection process or the implementation and design. How does one account for and balance the benefits and damages from an environmental cleanup process? Where are the more aggressive technologies justified? What technologies are appropriate for sites where contamination levels are relatively low? A broad-based balancing of risk and benefits and a careful matching of technology solutions to environmental needs may prove useful in optimizing environmental policies.

CONTAMINATED GROUNDWATER

Groundwater contamination problems can be broken down into 3 regimes spatially and temporally based on contaminant concentration, Figure 1. The first regime has very high contaminant concentrations resulting in perturbed geochemistry and requires aggressive remediation techniques. For example chlorinated volatile organic compounds (CVOCs) present as a separate liquid phase in pores can be removed using steam injection, electrical resistive heating, or excavation. These actions reduce contaminant concentrations rapidly and remove a large portion of the initial mass but typically leave behind enough contaminant to exceed NPDWRs by several orders of magnitude for decades. The regime with high concentrations is remediated with active measures that are less aggressive than in the very high regime and consist of techniques such as groundwater recovery and treatment, insitu chemical oxidation, and bio-remediation. During this regime the contaminant concentrations begin to decrease at a much slower rate than in the first regime and the remedial actions become less efficient on a mass recovery basis.

Finally the third regime is reached where contaminant concentrations only exceed the NPDWRs by 1 -2 orders of magnitude and contaminant concentrations have stabilized at a level above the NPDWRs. Remediation at this point is resource intensive and the remedial action may begin to cause more harm than good. This is because at the relatively low contaminant concentrations large quantities of water must be removed to remove a meaningful amount of contaminant. Furthermore, increasing amounts of energy must be used to remove the next unit of mass, greatly increasing the carbon footprint of the remedial action through the emission of green house gases associated with energy production. In this regime it is best to use passive techniques to bring the collateral damage resulting from remediation in line with the incremental improvement of environmental quality.

If we define water intensity as the amount of water necessary to remove one pound of contaminant we can then evaluate a groundwater remediation system with regard to resource conservation. Likewise we can evaluate the energy efficiency of a groundwater remediation system by studying the energy intensity or kWhr/pound of contaminant removed. And finally, the carbon intensity (lb CO_2/ lb contaminant) can be determined from the energy intensity using readily available data from the power industry.

Figure 2 shows the performance of an example groundwater pump and treat system for trichloroethylene that began operation in 1996. The system operates at nominal 70 gallons per minute and uses air stripping to remove CVOCs from the groundwater. Treated water is discharged out a permitted NPDES outfall that flows to the Savannah River. For the first ½ year of operation, influent concentrations are high and 100,000 to 500,000 gallons of groundwater are removed for every pound of TCE removed. From 0.5 to 7.5 years the influent concentration is moderate ($0.5e^{-3}$ to $1.0e^{-2}$ times solubility) and the water intensity of the treatment increases from 500,000 gallons/pound removed to 3,000,000 gallons/pound removed. If we forecast out 20 more years of operation the influent concentration decreases from 40 ug/L to 15 ug/L and the water intensity increases to 9,000,000 gallons/pound. At this point in the remediation the TCE concentration is still 3x the NPDWR and it is forecasted that at least 20 more years of operation will be required to reach the NPDWR.

Similar to the exponential growth in water intensity, the carbon intensity of the remediation system grows exponentially to 50,000 lb CO_2 / pound of contaminant removed. This example illustrates the continuously increasing environmental burden active remediation systems cause when they are operated to reduce groundwater concentrations down to the NPDWRs.

This graph typifies a performance characteristic of almost all environmental clean-up technologies. Such technologies work well when they are properly matched to the target problem, but they are wasteful and potentially damaging if improperly applied and they tend to become increasingly inefficient as conditions change over time.

WHAT'S NEXT?

During the past forty years, the global community has actively pursued policies to identify potential environmental threats and to develop clean-up and restoration solutions. In most areas of the developed world, this ground-breaking effort has led to a significant improvement in the environmental quality. This period can be characterized as a time during which an individual policy or solution was often developed in response to specific issue. There was minimal effort to coordinate and assess each policy in terms of its broader impacts and there was minimal consideration of sustainability. The "isolationist" model of environmental policy development often led to a risk transfer cycle in which collateral impacts and lost environmental services are not considered or valued. Such approaches are yielding to a more integrated view.

There is an emerging awareness of the importance of sustainability in all aspects of society and of the value of an integrated cross-cutting approach to environmental policy development. These trends are fueling the development of entirely new paradigms that build on the successful technical and institutional underpinnings of the past, while considering the broader implications of alternative solutions. Such change does not come easily or quickly. It requires careful and methodical effort and careful consideration of stakeholder values and inputs. The transition needs to be technically based and implemented in an open and disciplined fashion. Recent literature documents several examples of key ideas related to sustainability and integration.

- Explicit consideration of collateral damages such as energy use and loss of resources and environmental services in decisionmaking (Hauschild, 2005)
- Development of alternative metrics for tracking progress that account for some of the collateral impacts of the activity (National Research Council, 1997)
- Development of natural resource damage assessment systems to encourage the restoration of resources and to provide a technical basis for remedial investments (NJDEP, 2003)
- Development of policies that encourage better matching of technologies to environmental problems and the transitioning of technologies over the life of a project to maintain such a match (e.g., ITRC, in press)
- Development of environmental restoration systems that are based on ecological systems and ecological principles (e.g., ITRC, 2006; Berwick, 2000).
- Development of entirely new economic models that attempt to provide a consistent basis for balancing the disparate factors that influence a decision in equivalent units (e.g. Odum, 1996)

These are specific examples that represent a first wave of potential environmental policy development directions. Ideas such as these represent advancements on the path toward to the consideration of the *overall welfare of the environment* as a prime objective and which support, by analogy, the medical admonishment, *"First, do no harm."*

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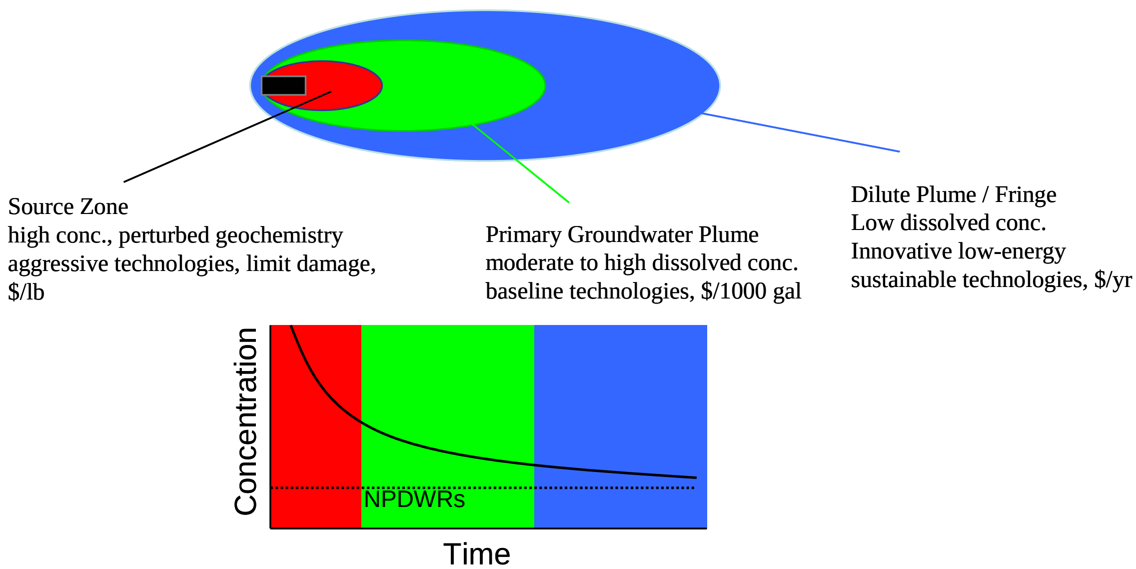

Figure 1 Spatial and temporal concentration regimes for a groundwater plume.

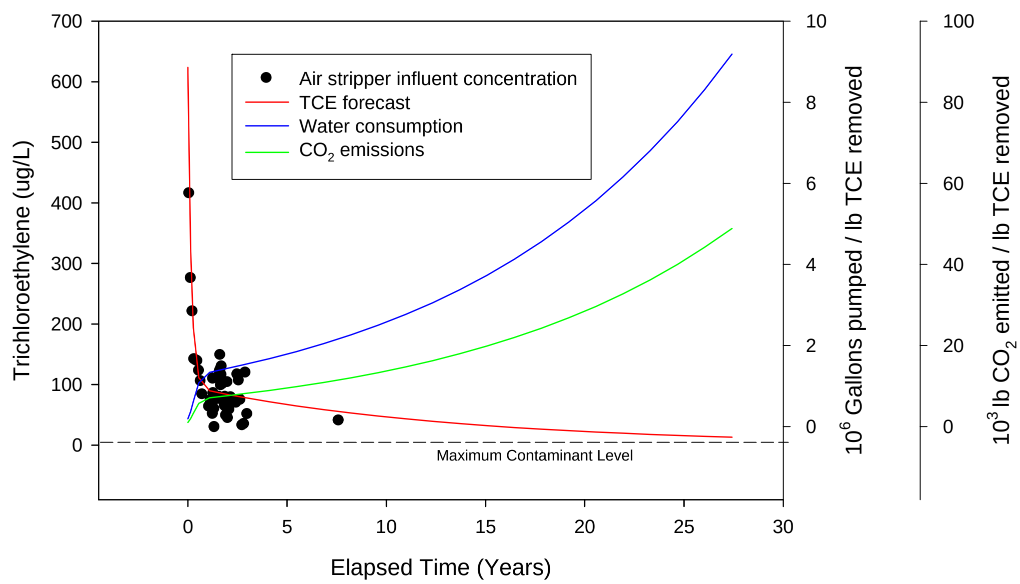

Figure 2 Groundwater remediation system performance and associated environmental burden.