

# Shortcomings in the NRC Groundwater Remediation Regulations

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The current regulations regarding groundwater remediation are severally lacking. They leave regulatory organizations little to no guidance on how to actually effectuate the remediation of groundwater when issuing permits, regulating those permits, and ordering companies to clean up spills they may have caused. There has been much research on modeling different systems of groundwater remediation, and this research has yet to be integrated into the formation of remediation regulations. This paper will discuss the current state of the law dealing with groundwater remediation, discuss some of the models created, and lay out ideas in how to integrate these models effectively.

## **I. Current Regulations**

The current system is made up of several regulatory agencies that control various industries, but, in the realm of groundwater remediation, end up doing the same thing. The Nuclear Regulatory Commission (NRC) regulates every area of nuclear operations, beginning with uranium mining, following through with the building and supervision of nuclear power plants, and regulating the disposal of radioactive waste.<sup>1</sup> Throughout the NRC permitting process plans are to be created in the case of groundwater contamination, including how any such spills are too be cleaned.<sup>2</sup> However, the regulations do not lay out how to make such determinations; all they require is that, “after weighing the environmental, economic, technical and other benefits against environmental costs and considering available alternatives, that the action called for is the issuance of the

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<sup>1</sup> U.S. Nuclear Regulatory Commission, *NRC: About NRC*, available at <http://www.nrc.gov>, (last accessed April 5<sup>th</sup>, 2010).

<sup>2</sup> 10 C.F.R. § 40.32 (2008).

proposed license, with any appropriate conditions to protect environmental values.”<sup>3</sup>

There is more detail on what some of the “appropriate conditions” are in Appendix A to 10 C.F.R. §40. The Appendix lists certain levels of various components that cannot be exceeded, lays out when and how to cap mine tailings, and goes into great detail in how certain environmental hazards are to be prevented. However, if groundwater does become contaminated, the regulations are quite brief:

5D--If the ground-water protection standards established under paragraph 5B(1) of this criterion are exceeded at a licensed site, a corrective action program must be put into operation as soon as is practicable, and in no event later than eighteen (18) months after the Commission finds that the standards have been exceeded. The licensee shall submit the proposed corrective action program and supporting rationale for Commission approval prior to putting the program into operation, unless otherwise directed by the Commission. The objective of the program is to return hazardous constituent concentration levels in ground water to the concentration limits set as standards. The licensee's proposed program must address removing the hazardous constituents that have entered the ground water at the point of compliance or treating them in place. The program must also address removing or treating in place any hazardous constituents that exceed concentration limits in ground water between the point of compliance and the downgradient facility property boundary. The licensee shall continue corrective action measures to the extent necessary to achieve and maintain compliance with the ground-water protection standard. The Commission will determine when the licensee may terminate corrective action measures based on data from the ground-water monitoring program and other information that provide reasonable assurance that the ground-water protection standard will not be exceeded.<sup>4</sup>

As can be seen, this process relies on what the licensee says will be effective and gives the NRC no guidelines on determining this themselves or ways to instigate their own plans. In this situation the NRC is entirely dependant on the licensee, while all the other regulations provided in Appendix A to 10 C.F.R. § 40 lay out in great detail what the licensee is required to do.

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<sup>3</sup> Id.

<sup>4</sup> 10 C.F.R. § 40 Appendix A (2008).

One example of the faults that this system leads to is the case of *Morris v. U.S. Nuclear Regulatory Commission*.<sup>5</sup> In this case the NRC issued a permit to HRI, a mining company that was planning on setting up four uranium mines. In *Morris* several groups challenged this permit, and one of the grounds that it was challenged on was the portion on what would be done if there was contamination of the groundwater. The NRC had no data on how such a procedure would be completed, so they relied on tests performed by the mining company when determining if the plan the mining company set forth was valid and would result in clean groundwater.<sup>6</sup>

HRI's proposed plan involved:

...flushing the aquifer with naturally occurring groundwater and decontaminated water to remove any remaining lixiviant and degraded groundwater. Affected water in each mine unit being restored would be withdrawn ..., processed through [the] ion exchange to remove uranium, then treated to remove radium and total dissolved solids. This treated water, known as permeate, would then be reinjected to further flush the aquifer. Groundwater sweep and permeate injection would be balanced so that a cone of depression would be maintained, causing groundwater to flow toward the mining unit. Thus, natural groundwater would be drawn into the mining unit's center.<sup>7</sup>

This is a description of a dipole flow system for cleaning an aquifer. One of the strengths of this system is that it draws all surrounding water into the system to be cleaned, preventing contaminants from spreading any further. However, the volume of water that must be pumped in order to clean the contaminated area still needs to be determined. For this, you need small-scale tests.

The standard way to scale up small-scale tests into large-scale sites is to measure "pore volumes." A pore volume is the amount of water held in porous material; in other

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<sup>5</sup> *Morris v. U.S. Nuclear Regulatory Com'n*, 598 F.3d 677, (10<sup>th</sup> Circuit, 2010).

<sup>6</sup> *Id* at 696.

<sup>7</sup> *Id*.

words, it is the amount of water in the system or the aquifer.<sup>8</sup> The term is used to describe how much water must be pumped through the system in order for the groundwater to be cleaned. If it takes twelve pore volumes to clean a certain kind of spill, then twelve times the water in the aquifer must be sent through the filtering process to ensure that the aquifer is clean. As will be discussed later in the paper, the use of pore volumes is problematic if the oversight of the well system overall is lacking. There are several ways to pump the required number of pore volumes while falling short of cleaning the entire aquifer, saving time and money for companies required to do so, but costing society and the ecosystem by leaving contaminated water in the aquifer.

In *Morris* the argument over the proposed remediation system was the number of pore volumes that HRI, the mining company, would have to run through the filtration system in the event of a spill.<sup>9</sup> The tests used to determine this were the small-scale tests conducted by HRI; there were no independent tests done by the Nuclear Regulatory Commission.<sup>10</sup>

Mathematical models have existed for some time that show how dipole wells actually work when installed, as well as models that show the downfall of some types of dipole wells. However, none of the regulations take this into account, and regulatory agencies remain at the mercy of those applying for licenses to provide the technical details necessary for them to make their decisions.

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<sup>8</sup> T. Karvonen, *Pore Volume/e*, available at [http://www.water.tkk.fi/wr/kurssit/Yhd-12.126/oppimateriaali/pore\\_v\\_e.htm](http://www.water.tkk.fi/wr/kurssit/Yhd-12.126/oppimateriaali/pore_v_e.htm) (last accessed April 5<sup>th</sup>, 2010).

<sup>9</sup> *Supra* 5 at 687.

<sup>10</sup> *Id.*

## II. Mathematical Models

The basis of any mathematical modeling dealing with water in aquifers, and all non-porous materials in general are Darcy's Law and Stokes' Stream Function. Darcy's Law was discovered in 1856 by Henry Darcy, and was based on experiments he had conducted in 1855 and 1856 with water in beds of sand.<sup>11</sup> Darcy's Law is a form of the Law of Conservation of Momentum, and it shows the relationship between the amount of water discharged through the medium, the hydraulic head (i.e. the pressure gradient, which is the change in pressure over a length), and the hydraulic conductivity (i.e. the porosity). This relationship is:

$$q = \frac{-\kappa}{\mu} \nabla P$$

In the above equation,  $q$  is the total discharge,  $K$  is the conductivity (porosity), and  $\mu$  is the viscosity of the fluid. As this relationship shows, the viscosity of the fluid creates a slower discharge; and the larger the pressure gradient and/or the greater the porosity the faster the discharge.<sup>12</sup>

While Darcy's Law is fairly simple, it is also very limited in scope. More useful is the Navier-Stokes Equation. However, this is a very complex equation that takes into account the relationship between the conservation of mass, momentum, pressure, species and turbulence.<sup>13</sup> While this equation was found almost two-hundred years ago, its use

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<sup>11</sup> Darcy's Law – Everything About Darcy's Law, *available at* <http://www.spiritus-temporis.com/darcy-s-law/> (last accessed April 5<sup>th</sup>, 2010).

<sup>12</sup> Id.

<sup>13</sup> A Brief History of Computational Fluid Dynamics, *available at* <http://www.fluent.com/about/cfdhistory.htm> (last accessed April 5<sup>th</sup>, 2010).

was very limited. The equation leads to very complex non-linear differential equations, which were practically impossible to use until the advent of more powerful computers in the 1960's and 70's.<sup>14</sup> However, some forms of the Navier-Stokes Equation have been solved and can now be used quite simply. Mathematicians have used these forms to model various wells and determine what scenarios are most effective in groundwater remediation. The Navier-Stokes Equation is quite useful when studying flow in an aquifer created from various remediation techniques because it is symmetrical about a single axis. Since the well system itself creates an axis, the model derived from the Navier-Stokes Equation flows out in every direction from the well in the same manner. This creates three dimensional models that can be used to simulate exactly how water flows through the aquifer when such a well is placed.

In order to create these models, certain facts about the aquifer must be found. The regulations already contain the answer to this, in that they require an applicant for a permit to find certain characteristics of an area before they begin any project:

The characteristics of the underlying soil and geologic formations particularly as they will control transport of contaminants and solutions. This includes detailed information concerning extent, thickness, uniformity, shape, and orientation of underlying strata. Hydraulic gradients and conductivities of the various formations must be determined. This information must be gathered from borings and field survey methods taken within the proposed impoundment area and in surrounding areas where contaminants might migrate to ground water. The information gathered on boreholes must include both geologic and geophysical logs in sufficient number and degree of sophistication to allow determining significant discontinuities, fractures, and channeled deposits of high hydraulic conductivity. If field survey methods are used, they should be in addition to and calibrated with borehole logging. Hydrologic parameters such as permeability may not be determined on the basis of laboratory analysis of samples alone; a sufficient amount of field testing (e.g., pump tests) must be conducted to assure actual field properties are adequately understood.

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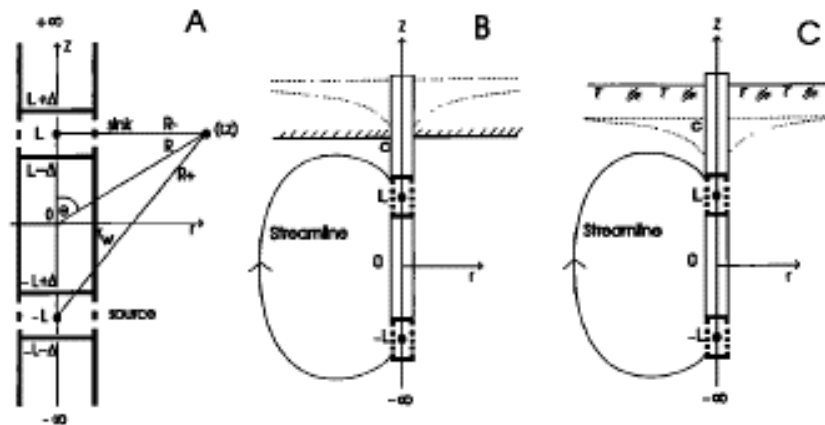
<sup>14</sup> Id.

Testing must be conducted to allow estimating chemi-sorption attenuation properties of underlying soil and rock.<sup>15</sup>

### A. Dipole Flow Models

As evidenced by the *Morris* case above, the dipole well model is used extensively in groundwater remediation scenarios. The dipole well consists of a long well with two screened sections at either end, one of which takes in water and one of which dumps it out. The water can be pumped to the surface and released underground again at the screened section, allowing for the filtration, cleaning, and introduction of remediating chemicals into the aquifer. These wells are used often for a variety of reasons. Since a single shaft can be used, it is very easy, fast, and cheap to put it into place. As will be shown in later, all surrounding groundwater will be drawn into the well, preventing further contamination. While these basic properties have been known for quite some time, the actual flow and its rate were not calculated until 1996.

A simple example of a dipole well and the flow it creates is shown below:



**Figure 1.** Schematic diagram of dipole in (a) infinite, (b) confined semi-infinite, and (c) unconfined semi-infinite aquifers.

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<sup>15</sup> 10 C.F.R. §40 Appendix A Section 5G

As can be seen from above, the dipole well creates streamlines that extend out into the aquifer, moving water far from the well itself and drawing in water from throughout the aquifer. This can pull in water from a wide source, and is very effective for groundwater remediation. However, these systems do have their drawbacks. The farther out from the well that you go, the longer the streamlines, which creates a longer path for the water to follow and a longer amount of time for the cycle to complete. Because of this, dipole systems are only useful for smaller, point-source contaminants. However, most new pollutants are caught quickly before they are spread throughout the aquifer, and a dipole system is very effective at containing contaminants before they can spread. In these limited capacities dipole wells are very useful, and an understanding of them is necessary if they are to be effectively used.

For the simplest form of the equation to be used, an infinite aquifer must be assumed. However, for any aquifer that is at least as wide as the distance between the extraction and the injection points of the well, the aquifer boundaries do not have an effect on the equations.<sup>17</sup> Because of this, most aquifers will fall under the much simpler equations governing flow in an infinite aquifer:

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<sup>16</sup> Zlotnik, V. and G. Ledder, *Theory of dipole flow in uniform anisotropic aquifers*, Water Resources Research, Vol. 32, No. 4, pg 1119, 1120 (April 1996).

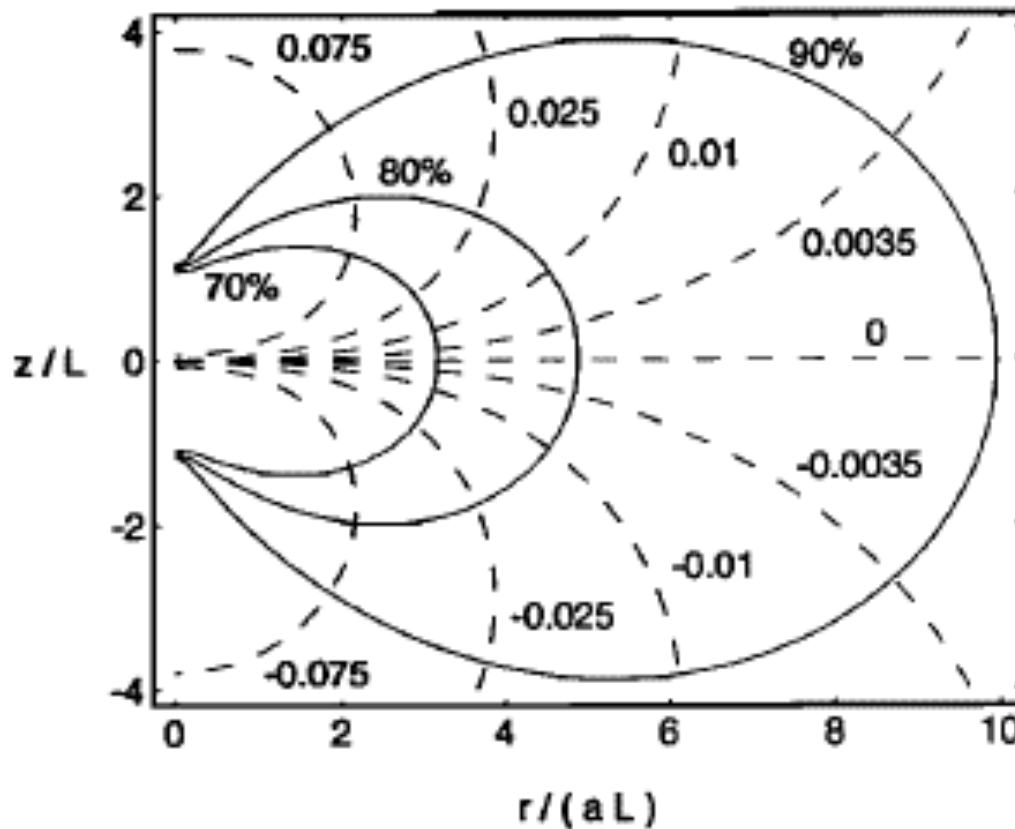
<sup>17</sup> Peurseem, D.V., V. Zlotnik, and G. Ledder, *Groundwater flow near vertical recirculatory wells: effect of skin on flow geometry and travel times with implications for aquifer remediation*, Journal of Hydrology 222, pg 109, 110 (1999).

$$S_{\infty} \sim q \left[ \ln \left( \frac{4\Delta}{\rho_w} \right) - 1 - \frac{L - \Delta}{2\Delta} \ln \left( \frac{L - \Delta}{L} \right) - \frac{L + \Delta}{2\Delta} \ln \left( \frac{L + \Delta}{L} \right) \right].$$

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While this equation appears complex, it is actually just a simple matter of plugging in the numbers. In fact, any graphing calculator can solve the above equation. Doing this for a specific aquifer will give the streamlines created by the dipole well, which in turn give the length of time needed to gather the water from as far from the well as needed.

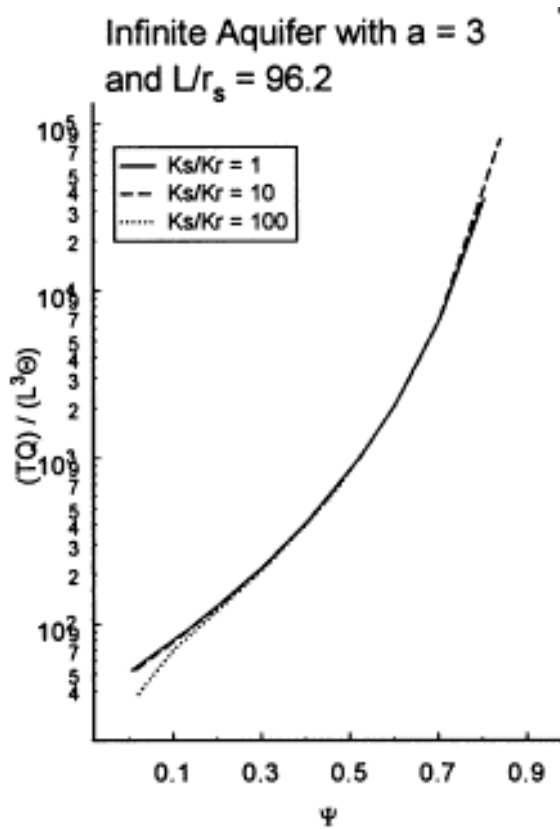
Using this equation you can create a simple graph of the path various particles of water will follow through the aquifer:



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<sup>18</sup> Supra 16 at 1123.

This shows that the majority of the water displaced by the well will fall within five times the length between the screened sections of the well. Since the equation describing the streamlines is parabolic it has an infinite reach. This means that some of the water will travel an infinite path between the extraction and injection chambers of the well. While dipole wells have a theoretically infinite reach and one well could potentially clean an entire aquifer, the travel times for these outer paths increase along with their distance. This is illustrated in the following graph of the travel times for various streamlines encapsulated a certain percentage of the water pumped:



For reference,  
 $10^5$  (90%)=274 years  
 $10^4$  (70%)=27 years  
 $10^3$  (50%)=2.7 years

This means that the streamline that would encapsulate an infinite distance would take an infinite amount of time to traverse, a very impractical exercise when trying to clean an

<sup>19</sup> Id at 1124.

<sup>20</sup> Supra 17 at 118.

aquifer. This is why the use of dipole wells is limited to smaller, point-source contaminants. For a practical matter, three years is approaching the limit for a reasonable amount of time to run a clean-up operation. This means that you only have enough time to allow for the 50% streamline, reaching about twice as far into the aquifer as the well is long. If the cleanup requires a farther reach, the dipole well method is simply impractical, or more than one well must be used.

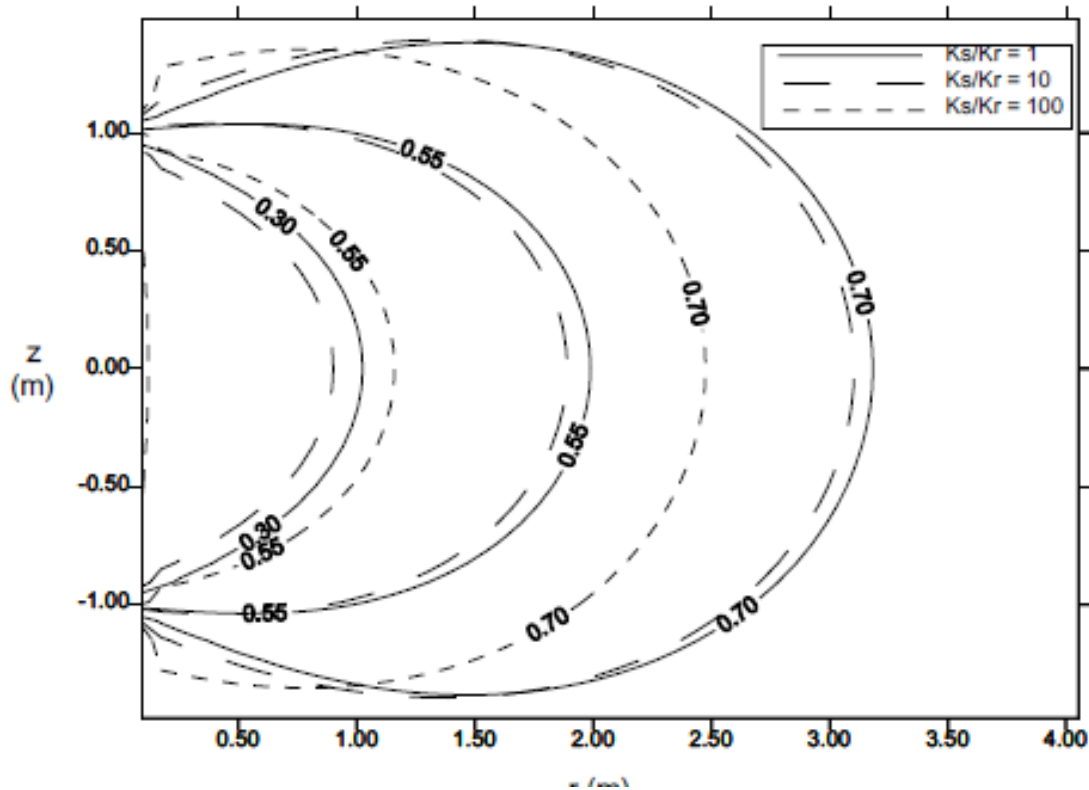
### **B. Effect of Skin Layer on the Dipole Well**

One way polluters can use a lack of knowledge on dipole well systems is to take advantage of the skin layer. When drilling a hole to put in a dipole well, an area of ground wider than the well must be drilled. After the well is put into position, this area must be backfilled with porous material. This backfill creates a skin layer around the well. The effect of using different types of materials of differing porosity to form the skin layer was studied in depth by D.V. Peurseem, et al in 1999.<sup>21</sup> It was found that skin material of more porosity greatly decreases the streamlines of the water through the aquifer, which in turn greatly decreases the amount of water that actually gets cleaned. When ordered to clean up contaminants, companies can use this to their advantage by being able to pump their pore volumes faster, saving money for the company but leaving the aquifer contaminated.

Below is a graph showing the effect of skins of various porosities on the streamlines:

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<sup>21</sup> Supra 17.



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In this graph, the solid line represents an ideal situation, where the hole is backfilled with material of exactly the same porosity as the soil around it. The dashed line represents the typical situation, where the backfill is slightly (10 times) more porous than the surrounding soil. The dotted line represents a backfill of extremely (100 times) greater porosity, which amounts to a backfill of sand or gravel. As can be seen from the graph, when the skin layer is 100 times as porous as the surrounding material, thirty percent of the water recirculates directly through the skin layer, without entering the aquifer. This allows the water to flow very quickly, allowing for a faster pumping of the required pore volumes. Because of this, the regulations should require that the backfill used should be no more than ten times to porosity of the surrounding soil.

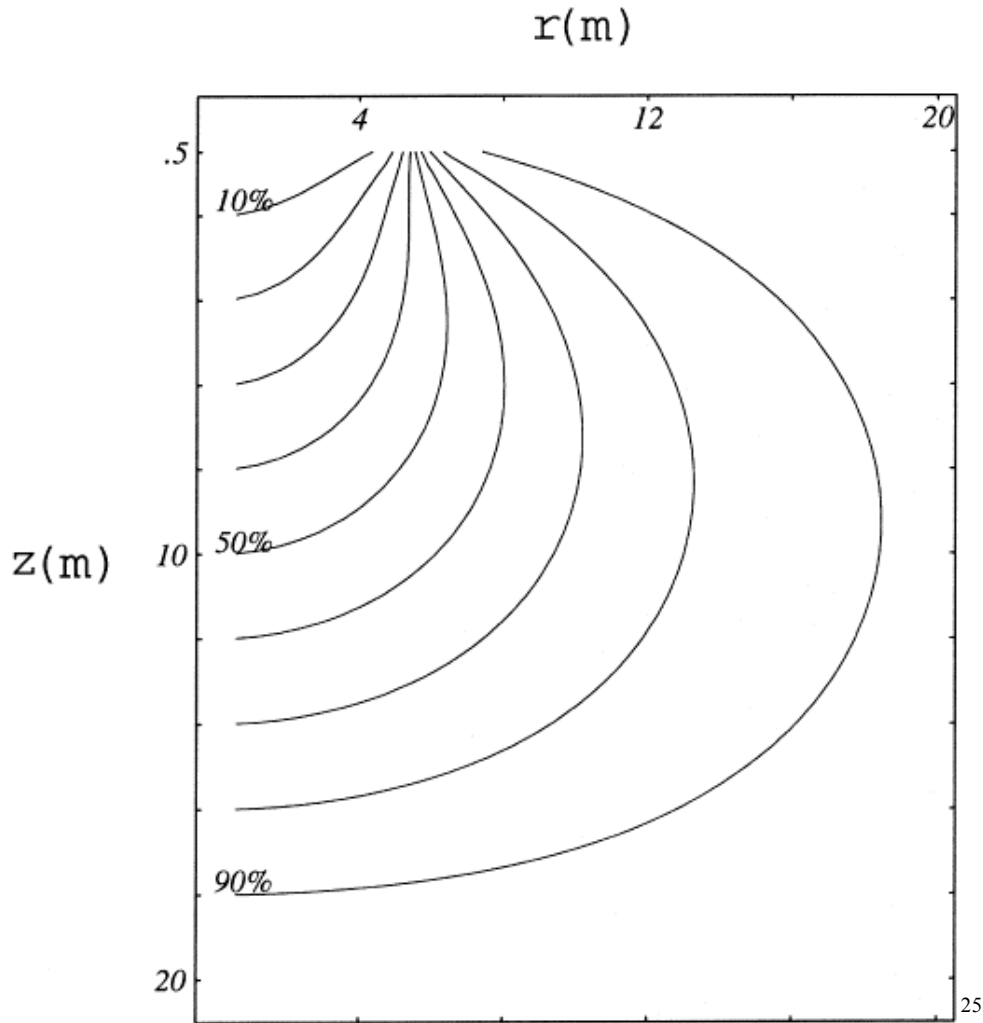
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<sup>22</sup> Id at 113.



The analysis of dipole circulation flow can be extended to apply to these remediation systems. This allows for easy computation of streamlines and travel times.

This results in the streamlines shown below:

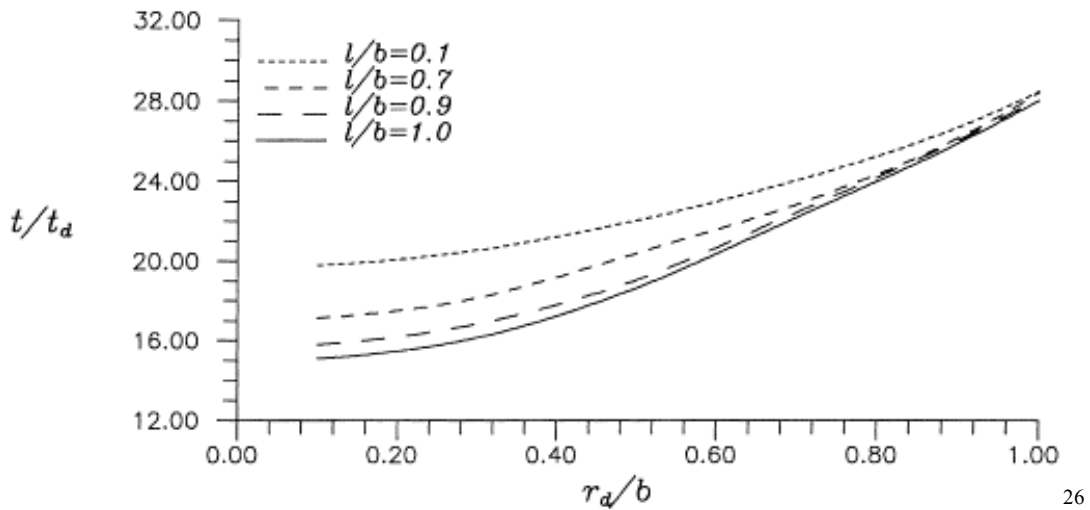
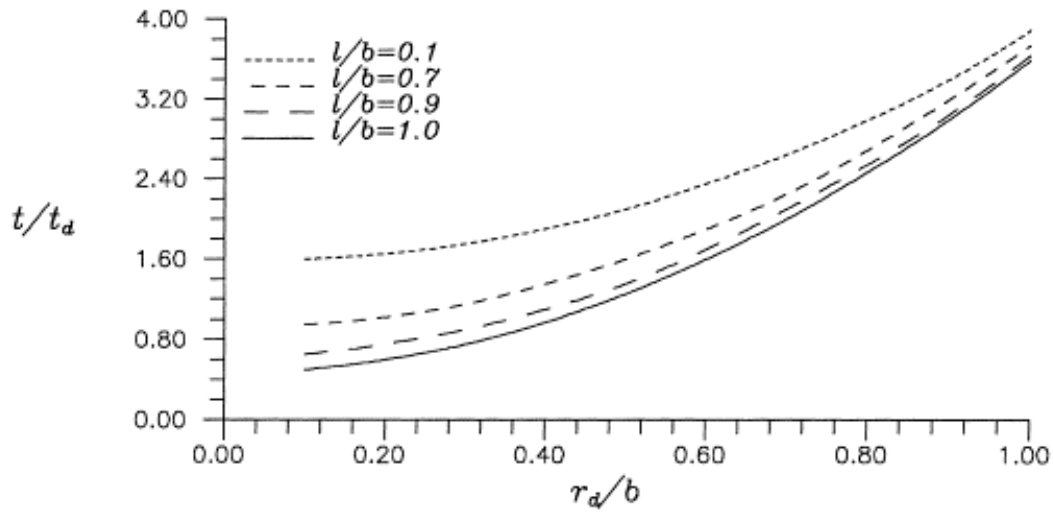


This shows that the streamlines of a trench system with a trench of radius 5.5 meters has an effective reach of almost 20 meters into the aquifer. This provides a much greater range than a dipole well system, allowing this system to be used in a wider array of scenarios.

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<sup>25</sup> Id at 369.

Additionally, the travel times along these streamlines are much faster than those along a dipole well. Below are the travel times for the fifty percent streamline and the ninety percent streamlines:



These graphs show the timelines of these wells. The different lines are the differing levels of penetration into the ground. As shown on these graphs, the travel times are considerably faster with this system than with a simple dipole system. Because of the

<sup>26</sup> Id at 372, 373.

broader reach and the faster travel times, the trench/tile well system is much more effective than the dipole system.

### **III. Recommendations for New Regulations**

Given what these mathematical models have shown us about the way that recirculation wells operate when used in an aquifer, the regulations concerning aquifer remediation should be changed to reflect this reality. There are several simple fixes that could be implemented to do so. Appendix A to 10 C.F.R. § 40 already contains detailed instructions for various requirements that a licensee needs to meet to get a permit, and adding some details to the very vague and hands-off 5D (the section dealing with groundwater remediation) would make the process more streamlined and safer, and would ensure that aquifers throughout the United States will remain free of deadly contaminants.

The first and foremost change in the regulations should be the easiest. As was shown above, the porosity of the skin layer greatly affects the amount of water that is sent through the aquifer. Currently, “pore volumes” is the standard measurement for laying out how long a company needs to clean an aquifer. Since using a more porous skin layer allows a company to recirculate water through a much faster timeline, avoiding sending it through the aquifer. This allows more pore volumes to be pumped more quickly, but leaves contaminants in the aquifer. Requiring companies to backfill their remediation wells with the original soil taken out of the ground while drilling would prevent them from doing this, and would protect groundwater quality.

Another change that should be inserted is to require the use of trench or tile recirculation systems whenever the contaminant needs to be removed quickly or if the contaminant has spread too far from the original site of contamination. The speed and reach of this system is vastly superior to the more often used dipole system, and should be required in most of the situations where a dipole system is used.

Since the regulations already call for certain qualities of the aquifer to be found before a permit will be issued, these properties can then easily be entered into the equations to find the travel times of whichever well system is to be used. This will give a time frame that can be used to determine how long a well should be run, removing the need for calculating pore volumes and making the entire process more accurate.

The regulations should still give the NRC a lot of discretion when determining if the submitted plan meets the requirement to clean the aquifer. The NRC should also have discretion to determine what kind of well to use, in case better remediation techniques are found; these should be implemented as soon as they are discovered and should not have to wait for further regulations to be put in place. However, if a dipole or a trench system is used the above recommendations should apply. Doing so will ensure that our groundwater remains clear of contaminants and denies polluters from performing various nefarious actions to save money at the expense of cleaning their pollution.